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At the U.S. EPA's Oil and Hazardous Materials Simulated Environmental Test Tank (OHMSETT) in Leonardo, New Jersey, from September 1975 through November 1975, the U.S. Environmental Protection Agency (US EPA) and the U.S. Coast Guard evaluated selected oil-spill control equipment for use on spills of floatable hazardous materials (HM). The HM used during the tests were octanol, dioctyl phthalate and naphtha. The major parameters indicating performance were recovery rates, recovery efficiency and throughput efficiency. It was concluded that equipment performance was directly relatable to the physical properties of the HM, and, in this respect, showed no difference from previous oil-recovery tests.

The conduct of the project is described; and the results, conclusions and recommendations are presented.

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PERFORMANCE TESTING OF SPILL CONTROL DEVICES ON FLOATABLE HAZARDOUS MATERIALS

by

William E. McCracken and Sol H. Schwartz
Mason & Hanger-Silas Mason Co., Inc.
Leonardo, New Jersey 07737

Contract No. 68-03-0490

Project Officers

Frank J. Freestone
Joseph P. Lafornara
Oil and Hazardous Material Spills Branch
Industrial Environmental Research Laboratory-Cincinnati
Edison, New Jersey 08817

This study was conducted in cooperation with

Department of Transportation
U.S. Coast Guard
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Washington, DC 20305
John R. Sinclair, Project Officer

INDUSTRIAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory -Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report describes the selection and testing at the Oil and Hazardous Materials Simulated Environmental Test Tank (OHMSETT) of several commercially available oil spill control devices for use in controlling spills of hazardous materials which float. These tests were conducted to determine the extent to which existing oil spill equipment could be employed to contain and/or remove other spilled hazardous materials. This report should be useful to Federal, State, and local government personnel as well as individuals in the private sector, who are interested in the prevention and control of pollution from oil and hazardous materials spills. Requests for further information should be addressed to the Resource Extraction and Handling Division, Oil and Hazardous Materials Spills Branch, Edison, New Jersey.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

ABSTRACT

At the U.S. EPA's Oil and Hazardous Materials Simulated Environmental Test Tank (OHMSETT) in Leonardo, New Jersey, from September 1975 through November 1975, the U.S. Environmental Protection Agency (U.S. EPA) and the U.S. Coast Guard evaluated selected oil-spill control equipment for use on spills of floatable hazardous materials (HM). The HM used during the tests were octanol, dioctyl phthalate and naphtha. The major parameters indicating performance were recovery rates, recovery efficiency and throughput efficiency. It was concluded that equipment performance was directly relatable to the physical properties of the HM, and, in this respect, showed no difference from previous oil-recovery tests.

The conduct of the project is described; and the results, conclusions and recommendations are presented.

A 16-mm color sound narrative motion picture entitled "Performance Testing of Spill Control Devices on Floatable Hazardous Materials" was produced to document the results of this project.

This report was submitted in fulfillment of Contract No. 68-03-0490 under the sponsorship of the U.S. Environmental Protection Agency. This report covers a period from September 1975 to November 1975 and work was completed as of September 1977.

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ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

cm --centimeter
cm^2/s --centimeters squared/sec
cSt --centistokes
m^3 --cubic meters
m^3/min --cubic meters per minute
m^3/s --cubic meters per second
CPM --cycles per minute
ft --feet
gal --gallons
gpm --gallons per minute
H/L --height to length steepness ratio
in --inch
IERL-Ci --Industrial Environmental Research Laboratory-Cincinnati, Ohio
I.M.E. --Industrial and Municipal Engineering
I.R. --infrared
kg --kilograms
kg/m --kilograms per meter
kt --knot
m --meter
m/min --meters per minute
m/s --meters per second
m^2/s --meters squared per second
mm --millimeters
mV/m/s --millivolts per meter per second
OHMSETT --Oil and Hazardous Materials Simulated Environmental Test Tank
p.p.t. --parts per thousand
% --percent
PACE --Petroleum Association for Conservation of the Canadian Environment
lbs --pounds
lbs/ft --pounds per foot
SSU --Saybolt Universal Seconds
sec, s --seconds
ft^2 --square feet
m^2 --square meters
V/m/s --volts per meter per second

SYMBOLS

U --Catenary boom configuration

SYMBOLS (continued)

V --critical velocity
J^c --Diversionary configuration
' --feet
" --inches
∞ --infinity
± --plus or minus next amount shown

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Test equipment for this project was supplied by the U.S. Environmental Protection Agency, the U.S. Coast Guard and several manufacturers of pollution control equipment. The cooperation of these Government agencies and the manufacturers is sincerely appreciated.

Mr. F.J. Freestone is the Project Officer of OHMSETT which is owned by the U.S. Environmental Protection Agency. His technical guidance and many valuable suggestions helped make this test project a success and were greatly appreciated.

Mason & Hanger-Silas Mason Co., Inc. is the operating contractor of OHMSETT and Mr. R.A. Ackerman, Manager provided overall project valuable guidance which is acknowledged with sincere thanks.

Mr. G.F. Smith, Head of the OHMSETT Chemistry Laboratory, provided valuable assistance and was responsible for the laboratory and pilot plant phase of this project, for which we are grateful.

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SECTION 1

INTRODUCTION AND OBJECTIVES

BACKGROUND

When classified by their physical behavior in water, all hazardous materials fall into one of four categories. First are the gases, substances that vaporize upon release. Second are the sinkers, substances that settle to the bottom of watercourses without dissolving. Third are solubles, substances which dissolve in water. On the last category, are the floaters, substances which remain at the surface without dissolving. The United States Environmental Protection Agency, Office of Research and Development together with the United States Coast Guard, Office of Research and Development has the responsibility of developing methods to prevent and control spillage of hazardous materials and has initiated research for materials in all four categories.

During this joint EPA USCG project, the two Agencies attempted to begin to define the conditions under which existing oil spill control and recovery equipment could be used to control spills of hazardous chemicals which fall into the last category, floaters.

Spills of some floatable hazardous materials can be controlled and cleaned up with equipment presently used for oil spills. The use of such equipment on a given HM spill depends upon many considerations, including: the safety hazards of the spilled material the chemical compatibility of the spilled material with the equipment; the expected performance of the equipment with the spilled material; and the limitations of the equipment with respect to existing environmental conditions. The toxicity, flammability and other critical properties of floatable HM can be found in handbooks (1, 2, 3). This report addresses the performance of oil-spill control equipment as tested with floating HM at OHMSETT. Seven of the nine devices tested had been previously evaluated for performance in oil under different test projects at OHMSETT (4, 5, 6).

OHMSETT is a test facility for performance testing and evaluation of full-scale and prototype equipment. (For details, see Appendix A.) Several reasons for conducting performance tests in a hydrodynamically controlled environment, such as OHMSETT, are:

- Tests cannot be legally conducted on the open waterways, without specific governmental approval.

- Ability to establish simulated hydrodynamic-environmental conditions.

- Ability to establish simulated oil (or HM) spills on open waterways.

- Ability to repeat the test conditions and results to allow statistical treatment of the data.

The above reasons allow standardized tests, which are necessary to quantify the performance of equipment with respect to design specifications. Ultimately, the results obtained will allow selection of the proper equipment for use in a specific spill situation.

SCOPE

The purpose of this project was to test and evaluate existing inland and harbor oil-spill control equipment for control and clean-up of the hazardous materials. Tests were performed on various skimmer designs of both the advancing and stationary type, barriers of different designs in both catenary and diversionary configurations, and a prototype mechanical sorbent deployment and retrieval system using polyurethane foam cubes.

Since there were several different types of test equipment, five test matrices were designed to simulate different field-use conditions (typical inland lakes, rivers and harbors), and to correlate with test data on oils taken earlier under the same test conditions at OHMSETT.

SELECTION OF MATERIALS

To expedite the selection of the HM to be used during testing, a pilot study was conducted on the use of HM at OHMSETT (Appendix B). Objectives were to:

- Assure compatibility of the OHMSETT equipment with the selected HM.

- Make the final selection of the HM to be used during testing.

- Develop safety procedures and practices to be used during testing.

The pilot study covered six chemicals whose compatibility with materials used in fabrication of oil-spill control equipment had already been determined. Tests were conducted a[illegible]e laboratory scale (jar tests), and at the pilot scale in an alumi[illegible]k with 1.13-m^3 capacity, (300 gal). A pilot-scale filtration unit [illegible]so constructed.

As a result of the pilot study, the following conclusions were reached:

- Octanol, dioctyl phthalate and naphtha were representative of 167 HM investigated by Rensselaer Polytechnic Institute for the

U.S. Coast Guard.

- They were relatively inexpensive, readily available, and compatible with the test tank and ancillary equipment. Safety equipment and procedures for handling were available.

- On-site filtering units were adequate for treating water containing the HM.

The hazardous materials selected for the tests were octanol, dioctyl phthalate, and naphtha. The test fluids represented a wide range of three important physical properties--viscosity, specific gravity, and interfacial tension. The HM were also selected for low toxicity and flammability. An investigation of possible HM to be tested was conducted by Rensselaer Polytechnic Institute (7).

The test design was also aimed at providing an understanding of the performance of several types of oil-spill control devices, under a variety of controlled conditions at OHMSETT.

SECTION 2

CONCLUSIONS

GENERAL

The following conclusions were drawn from evaluation of the test data and observations of equipment performance, during this project's tests involving HM and previous tests with oil conducted under Mason & Hanger Job Order No. 6 (5).

- Performance of the equipment is directly relatable to the physical properties of the test fluids, which points to the need to define the capability to control, confine, or process the various types of oil and/or HM released during spills for each type of device.
- Performance of the equipment, when used on the HM, did not vary substantially from performance when tested on oils of similar physical properties under the same conditions.
- The chemical properties of the HM must first be analyzed in terms of equipment operator safety, equipment durability and methods for its separation from water.

BOOM TESTS

The effect of HM specific gravity on boom performance was defined for the three chemicals tested. Head wave shedding and subsequent entrainment was the primary mode of failure: a phenomenon directly related to droplet formation and the relative velocity between the slick and the tank water. Boom performance (maximum tow speed before HM loss) increased with Naphtha, pointing to a significant relationship between specific gravity and boom maximum tow speed. Test fluids of relatively high specific gravity tended to become entrained via droplet formation and shedding loss occurred at the lower tow speeds in both the catenary and diversionary configurations.

Without waves, containment and diversionary success was limited when the booms were confronted with 1-mm thickness of DOP. The primary mode of failure was shedding, a phenomenon directly related to droplet formation and subsequent entrainment. Reviewing the comparative physical properties of test fluids, it can be noted that the difference between tank water and test fluid specific gravity was lowest when considering DOP (0.0345) and highest with Naphtha (0.2995). Boom performance increased with Naphtha pointing to a significant relationship between specific gravity and boom maximum tow speed. Test fluids of relatively high specific gravity tended to become entrained as the result of droplet formation and shedding loss occurred at lower tow speeds in both the catenary and diversionary configuration.

STATIONARY SKIMMER TESTS

Stationary skimmer performance was found not to be dependent upon the physical properties of the test fluids nor the wave conditions tested. Three different types of stationary skimmers were tested: floating suction head, self-adjusting weir and oleophilic rope types.

The floating suction head skimmer performed slightly better with the more viscous DOP (67.5 cSt) than with less viscous HM under a calm surface condition. When waves were introduced, however, the DOP tended to become mixed into the water column. Under this condition, the performance of the floating suction head skimmer was optimized with Naphtha. It is interesting to note that except with DOP, the nominal 0.6-m harbor chop did not significantly affect recovery rate.

The self-adjusting weir-type skimmer exhibited recovery efficiencies approaching 40% when tested with DOP and a calm surface condition. As with the floating suction head skimmer, efficiency was maximized with the higher density HM. When confronted with the wave condition, the total mixture recovery rate increased as more water was skimmed, but recovery efficiency dropped.

The third stationary design characteristic studied was the oleophilic rope type skimmer. Recovery efficiency approached 100% with DOP and a calm surface condition. Performance in waves was optimized near 80% recovery efficiency. Hydrodynamic forces were somewhat overcome by the adsorption force on the test fluid by the oleophilic rope.

ADVANCING SKIMMER TESTS

Similar to the stationary skimmers, the advancing skimmers were found to have a strong relationship between their performance and the physical properties of the HM and the design features and controls of each device. Two types of advancing skimmers were tested: dynamic inclined (non-absorbing) belt (DIP-1002) and floating weir box (ORS-125).

The DIP-1002 skimmer was tested with the following controlled settings:

- Belt speed = 1.22 m/s (2.42 kt)
- Tow speed - 0.25 to 1.27 m/s (0.5 to 2.5 kt)
- Notch opening = 1.9 cm (0.75 in)

- Slick width = 1.52 m (5 ft)
- Slick thickness = 2 mm (0.08 in)
- Tank surface condition = calm

The tow speed at which maximum performance occurred was dependent upon HM density. HM recovery rate was optimized for each test fluid with respect to increasing tow speed above 0.25 m/s (0.5 kt). The lower density Naphtha was best recovered at the relatively high tow speed of 1.14 m/s. Optimum recovery rate performance with DOP occurred at the lower tow speed of 0.25 m/s (0.5 kt). Except for DOP, the maximum recovery rates of all test fluids were comparable and it is possible that this recovery rate ($\simeq 1.3 \times 10^{-3}$ m^3/s (20.6 gal/min)) may have been reached with DOP at tow speeds lower than 0.25 m/s. Since speeds < 0.25 m/s are unacceptable for field use conditions, performance at these speeds was not considered of interest to the overall test program.

Since the intent of the dynamic inclined belt is to induce a flow velocity relative to the test fluid, a critical balance of belt speed to tow speed must be established for each given test fluid. For those fluids that tend to form large diameter droplets upon breakaway (DOP) and have a longer rise time, collection increases at lower current speeds because the droplets must rise into the oil collection well. As tow speed increases test fluid droplets rise behind the collection well and are drawn through the backplate opening and out behind the device. This was evidenced through performance data as well as visual observation. In the case of the low density Naphtha, it was possible to establish a higher flow velocity and successful collection since the rise time is faster. In fact, hihger flow velocities were required to move the test fluid to the collection well.

Throughput efficiency can be analyzed in much the same manner as recovery rate. Optimum efficiencies generally fell within the range of 40-60% with a maximum of 85% when tested with DOP. However, this 85% efficiency occurred at the minimum tow speed of 0.25 m/s (0.5 kt) which is too low for field use consideration.

In the case of the ORS-125, a weir type advancing skimmer, the following test conditions were established:

- Tow speed = 0.25 to 1.52 m/s (0.5 to 3.0 kt)
- Air supply to onboard pump = 300×10^3 N/m^2 (44 psi)
- Slick thickness = 4 mm (0.16 in)
- Slick width = 1.52 m (5 ft)
- Surface condition = calm

Performance was indicated by HM recovery rate, recovery efficiency, and throughput efficiency. A maximum throughput efficiency of 90% occurred when testing with DOP at 0.25 m/s (0.5 kt) and Lube oil at 0.63 m/s (1.25 kt). When confronted with the low density Naphtha, the device was unable to successfully collect material. The density dependence of the weir-type advancing skimmer was readily observed both visually and quantitatively.

SORBENT SYSTEM TESTS

The throughput efficiencies for the sorbent system, with a fixed tow speed of 1.02 m/s (2.0 kt), were quantitatively noted as being somewhat independent of test fluid property. Also, the device when subjected to "random" wave surface conditions, maintained a high throughput efficiency of between 60 and 80%. As in the results of the oleophilic rope, the effects of natural hydrodynamic forces which tended to cause high density materials to become entrained were reduced. The absorption rate of the sorbent material for various test fluids played an important role in effective spill removal. The sorbent system tested utilized polyurethane open-celled foam which absorbed material rapidly and was easily regenerated. Recovery efficiency was maximized at 80% in the no wave condition with Naphtha, with and without waves.

Recovery rate was optimized with octanol and was even higher with the 0.6-m harbor chop. However, the experimental determination of recovery rate was not as accurate as for throughput and recovery efficiencies.

SUMMARY

The following relationships are based on the evaluation of data available in the appendices of this report.

Test Device	Physical properties that affect performance
Boom	density, interfacial tension (I.F.T.)
Stationary Skimmer	density, I.F.T., viscosity
Advancing Skimmer	density, I.F.T., viscosity
Sorbent System	depends on compatibility with sorbent cubes; otherwise independent

SECTION 3

RECOMMENDATIONS

Equipment designed for the control and removal of floatable hazardous materials should have personnel safety and chemical compatibility as primary considerations. Where equipment design requires operator contact with contaminated components, Standard Operating Procedures should be followed, using such safety procedures, protective devices and clothing as specified. Equipment should be built with chemically inert materials for those components in contact with the HM, and should be capable of decontamination at the end of each test.

A program should be undertaken to develop techniques to define and measure the flow conditions surrounding spill control equipment. The techniques must be broad enough for use with virtually all equipment, both in tank testing and in the field. The program goals should include a capability to measure the critical levels of flow that result in formation and entrainment of droplets of the spilled fluid around and near any device. These techniques could form the basis for correlation of tank testing, field testing and field use.

A standard test should be defined to provide critical information as to the effect of HM on existing clean-up equipment, possible clean-up methods, and ultimate disposal of HM. The test should provide both qualitative answers and quantitative data on a practical, relatively inexpensive basis.

SECTION 4

FACILITY DESCRIPTION

OHMSETT DESCRIPTION

The OHMSETT facility is located in Leonardo, New Jersey, at the Naval Weapons Station Earle (for details see Appendix A). The facility was build specifically for the testing of containment and recovery equipment for oils and HM. Waves can be generated up to 0.9 m (3 ft) high and 45.7 m (150 ft) long, and current simulated with a towing bridge up to 3.1 m/s (6 kt). The tank can be filled with either fresh or seawater. The seawater of Sandy Hook Bay has a salinity of 20 ppt and was used during these tests.

DESCRIPTION OF MODIFICATIONS TO OHMSETT

Since the test equipment and conditions were to duplicate earlier tests at OHMSETT, no significant modifications were necessary to accomplish this test project. However, the HM did present a potential fire safety problem. Naphtha was the greatest concern, because of its low flash point of 37.8°C (100°F). Steps taken to offset this hazard included the liberal distribution of portable fire extinguishers, and the installation of two independent systems for alarm shutdown purposes. One system was based upon a vapor concentration detector and the other based upon a heat detector. Also, during the naphtha testing, a three-man U.S. Navy firefighting crew stood by with full equipment.

DESCRIPTION OF INSTRUMENTATION

The OHMSETT instrumentation system is designed to measure, record and document all of the physical parameters necessary to quantitatively evaluate the performance of the test devices. Fluid properties, fluid distribution rate, fluid recovery, ambient conditions, wave characteristics and tow speeds are measured as follows:

Fluid Properties--Samples of materials are collected prior to distribution and after recovery. Properties and the techiques which are used to determine them include:

Specific Gravity via	Laboratory hydrometers
Viscosity via	Shear-type viscosimeter & Flow-thru orifice visicosimeter

Temperature via	Laboratory thermometer and Portable I.R. thermometer
Surface Tension via	Tensiometer
Interfacial Tension via	Tensiometer
Percent Water via	Centrifuging with 50% water saturated toluene

Fluid Distribution Rate--This was measured using positive displacement flow meters. Upon signal from the test director, a predetermined amount of HM was distributed through an air-operated nozzle system in line with the flow meter.

Fluid Recovery--Measuring containers, sizes 0.06, 0.19, 0.38, 1.89 m^3 (15, 50, 100, 500 gal) were calibrated in gallons per inch. These containers were constructed of translucent poluethylene, enabling technicians to detect and measure the HM/water interface. If the thickness of either phase was less than 2.5 cm (1 in), that phase was drawn into 1.000 mm graduated cylinders for more accurate measurement. To ascertain that the HM phase contained minimal dispersed water droplets, centrifuge samples of the HM phase were routinely collected and analyzed. If the water content was more than 2.5%, a water content correction was employed.

The time required to allow complete settling of the water phase from the HM phase depended upon many factors, including the ambient temperatures, type of HM used, and the amount of mixing caused by the removal mechanism (i.e., pump, belt, etc.). A minimum settling time of 1/2 hour with continuous checks was standard procedure.

Ambient Conditions--The following parameters were measured and recorded prior to each test using the OHMSETT weather instrumentation: air and water temperature, wind speed and direction, relative humidity, and barometric pressure.

Wave Characteristics--The OHMSETT generated waves were routinely checked and photographically documented to measure the height, length, and period. Using a grid system superimposed on the east tank wall, technicians observed wave parameters and correlated their findings to the wave generator settings of stroke length and CPM.

Tow Speed--Data were acquired using a DC tachometer mounted on the motor shaft of the bridge drive. The gear ratio provided for 196.8 V/m/min, which was reduced by a voltage divider to 3.28 mV/m/min, and read by a three segment, 1 V digital voltmeter.

Miscellaneous Measurements--During these tests, some selected measurements were taken, recorded and reduced through an automated data acquisition system developed for the U.S. Coast Guard by the University of Rhode Island.

In addition to the recording of the above measurements, 16 mm motion picture and 35 mm slide records were made of the testing.

TEST EQUIPMENT RIGGING AND FLUID HANDLING

Procedures for all towing tests are substantially similar. The test device is connected by cables and/or ropes between the main towing bridge and a light truss, both of which span the tank and travel its length. The fluid for a test is contained in two tanks on the main towing bridge, and is pumped through a manifold and nozzle system for distribution onto the water surface. Test fluid is deployed several feet ahead of a device under test, during tow. Slick thicknesses are calculated based upon the speed of the tow, the slick width, and the flow rate of the pump. Slick widths are varied according to the arrangement of the nozzles as prescribed by the customer's recommendations. The device under test encounters the slick of test fluid, and contains it or diverts it. At the end of the run, the tank surface is skimmed clean on the return of the tow bridge to the starting position. Test fluids are refurbished for reuse according to the procedure outlined in Figure 1.

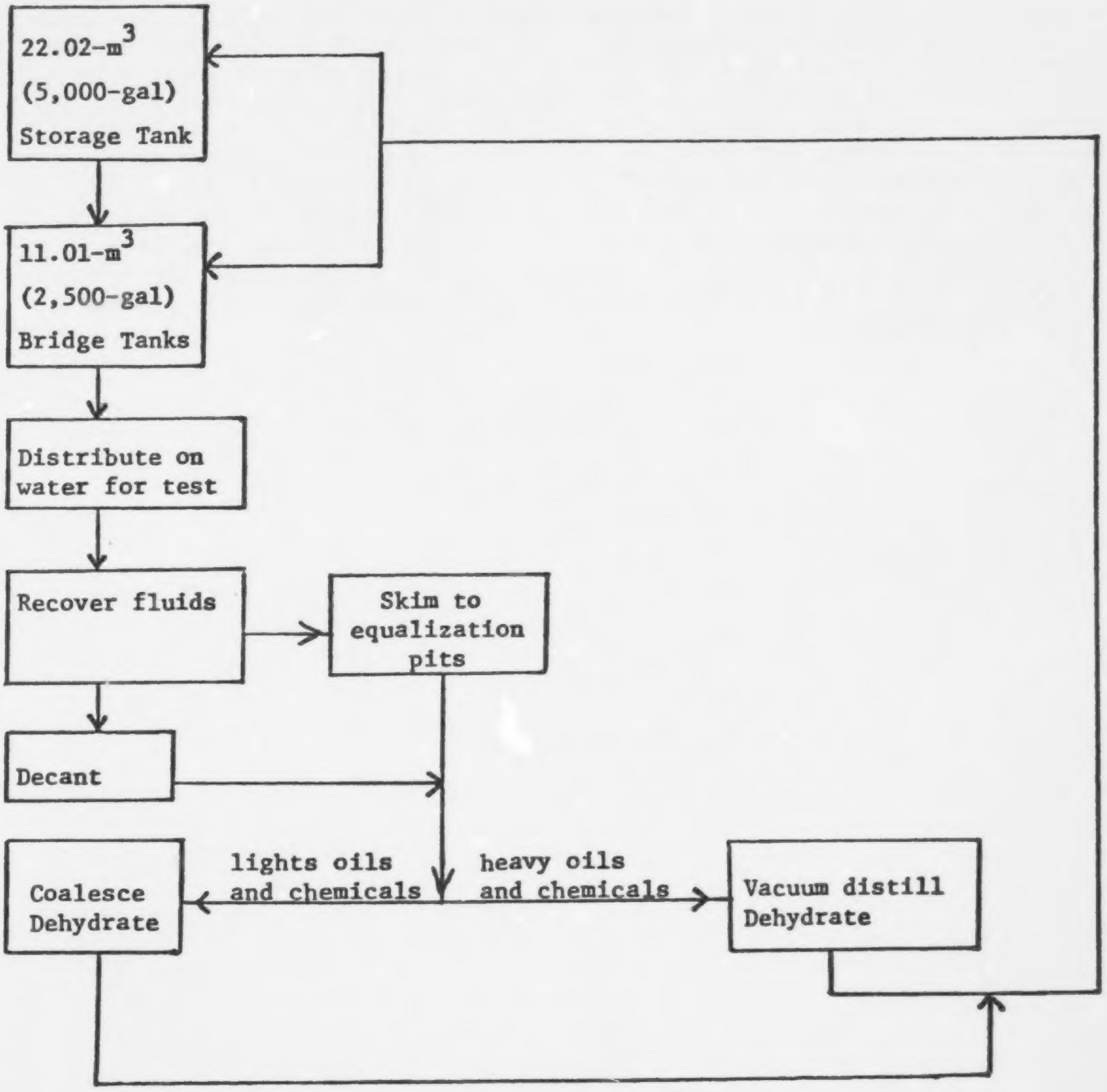

Figure 1. Fluids handling.

SECTION 5

TEST PLAN

TEST RATIONALE

Inland waterways, estuaries and harbors represent a wide spectrum of environmental conditions in terms of waves, currents, tides and water properties. Spill control equipment is designed to operate effectively only within certain limits of these environmental conditions. Thus, the wave characteristics and currents (as well as the HM) were selected to represent the more typical situations. Also, where possible, the HM test conditions were matched to earlier conditions when these devices were tested in oil (4, 5, 6). This provided a direct comparison of the performance of the equipment in HM and oil.

The HM selected were not destructive to the test equipment. Test equipment performance was tested primarily as a function of three HM physical properties: viscosity, specific gravity and interfacial tension. Table 1 gives the range on these properties as represented by the test fluids. Based on previous tests with oils (give in Table 1), the properties that affected performance most were viscosity and specific gravity.

EQUIPMENT TESTED

Equipment was selected on the basis of four criteria: that each major type of clean up device be represented; that each device have previously been tested with oils at OHMSETT; that the materials of construction of each device be compatible with the intended HM; and that each device be readily available for testing. The equipment selected was:

Booms

1. U.S. Coast Guard - Prototype High Seas Barrier
2. Clean Water, Inc. - Harbour Oil Containment Boom
3. B.F. Goodrich Sea Products - 18 PFX Seaboom

Sorbent System

1. U.S. Environmental Protection Agency - Developmental Sorbent System (developed under contract with Seaward International)

Advancing Skimmers

1. Ocean Systems, Inc. - ORS 125
2. JBF Scientific Corp. - DIP 1002

TABLE 1. PHYSICAL PROPERTIES OF TEST FLUIDS

Chemical / Property	Low Pressure Naphtha	Octanol	Dioctyl Phthalate	No. 2 Fuel Oil	Sunvis 75 Lube Oil
Freeze Point °C (°F)		-58 (-72)	-55 (-67)		
Boiling Point °C (°F)	156-198 (313-389)	194 (382)	230 (446)		
Flash Point °C (°F)	38 (100)	178 (353)	218 (425)		
Viscosity @ 24°C (75°F) x 10^{-6} m^2/s	5.8	12.0	67.5	8.5	100.0
Specific Gravity	0.710	0.827	0.975	0.849	0.870
Δ Sp. Gr. * (Avg.)	0.2995	0.1825	0.0345	0.1605	0.1390
Vapor Pressure (mm Hg)	2.0 @ 20°C	0.2 @ 20°C	1.2 @ 200°C		
Surface Tension x 10^{-3} N/m	22.5	24.8	28.2	25.4	28.0
Interfacial Tension x 10^{-3} N/m	25.4	14.8	15.2	9.0	25.0

***Tank Water Specific Gravity = 1.0095**

Stationary Skimmers

1. Industrial and Municipal Engineering (I.M.E.) - Swiss OELA III
2. Slickbar Inc. - 1-in Rigid Manta Ray
3. Oil Mop Inc. - Mark II-D

(For detailed descriptions of the equipment tested, refer to Appendices C, D, E, and F).

TEST CONDITIONS

The test matrix for the full-scale investigation duplicated the matrix conditions previously used for each device during previous OHMSETT testing with No. 2 fuel oil and a lubricating stock oil (5). The matrix was designed around variations in wave conditions, tow speeds and slick conditions, with the variable parameters chosen to be appropriate to the device being tested.

Booms were tested with the three HM at a slick thickness of approximately 1 mm (0.04 in) and width of 9.14 m (30 ft), at each of three wave conditions in both catenary and diversionary modes of operation (Tables 2, 3). Exceptions were: 1) the U.S. Coast Guard Boom was not designed for diversionary use, and therefore was not tested in that mode, and 2) some of the matrix points in the schedule were not achieved, due to time limitations.

Stationary skimmers were tested (Table 4) in slicks of 12 mm thickness (0.5 in) with three HM, under conditions of calm and a 0.6 m (2 ft) harbor chop. The tests were designed to yield information on recovery rate and volumetric efficiency.

Advancing skimmers were tested (Tables 5, 6) in a recovery versus tow speed matrix, for three HM, under calm conditions in slicks 2-4 mm thick (0.08-0.16 in) and 1.52 m wide (5 ft). These tests were designed to yield curves of recovery rate, volumetric efficiency (percent spill material in recovered fluids) and throughput efficiency (volume recovered/volume encountered) versus tow speed.

The sorbent system was tested (Table 7) at a speed of 1.02 m/s (2 kt) with three HM, at a fixed slick condition of 4.5 m (15 ft) width and 0.5 m (0.2 in) thickness, and under three wave conditions: calm, a 0.3 m (1 ft) harbor chop and a 0.6 m (2 ft) harbor chop. These tests were designed to yield information on throughput efficiency and HM recovery rate.

TABLE 2. BOOM TEST MATRIX CATENARY CONFIGURATION

Test no.	Test fluid	Tow speed* (m/s)	Wave character height, length, period [m (ft), m (ft), s]	Wave generator eccentric cm (in), GPM
S-1	None -	V_c ± (0.25)	no wave	
S-2	stability	V_c ± (0.25)	0.6 (2) harbor chop	7.62 (3.0), 30
S-3	tests	V_c ± (0.25)	0.3 (1) harbor chop	3.81 (1.5), 40
S-4		V_c ± (0.25)	0.6 (2), 9.1 (30), 3.0	11.43 (4.5), 20
1	DOP	V_c ± (0.25)	no wave	
2	DOP	V_c ± (0.25)	0.6 (2), 9.1 (30), 3.0	11.43 (4.5), 20
3	Octanol	V_c ± (0.25)	no wave	
4	Octanol	V_c ± (0.25)	0.3 (1) harbor chop	3.81 (1.5), 40
5	Octanol	V_c ± (0.25)	0.6 (2), 9.1 (30), 3.0	11.43 (4.5), 20
6	Naphtha	V_c ± (0.25)	0.3 (1) harbor chop	3.81 (1.5), 40
7	Naphtha	V_c ± (0.25)	no wave	
8	Naphtha	V_c ± (0.25)	0.6 (2), 9.1 (30), 3.0	11.43 (4.5). 20

*Boom performance was observed up to failure and detailed observation was utilized at ±0.25 m/s (0.5 kt) relative to that failure point.

TABLE 3. BOOM TEST MATRIX DIVERSIONARY CONFIGURATION

Test no.	Test fluid	Tow speed m/s	Wave character height, length, period m (ft), m (ft), s	Wave generator eccentric cm (in), CPM
S-1	None - stability tests	V_c ± (0.25)	no wave	
S-2		V_c ± (0.25)	0.6 (2), 9.1 (30), 3.0	11.43 (4.5), 20
S-3		V_c ± (0.25)	0.3 (1) harbor chop	3.81 (1.5), 40
1	DOP	V_c ± (0.25)	no wave	
2	DOP	V_c ± (0.25)	0.6 (2), 9.1 (30), 3.0	11.43 (4.5), 20
3	Octanol	V_c ± (0.25)	0.6 (2), 9.1 (30), 3.0	11.43 (4.5), 20
4	Octanol	V_c ± (0.25)	no wave	
5	Octanol	V_c ± (0.25)	0.3 (1) harbor chop	3.81 (1.5), 40
6	Naphtha	V_c ± (0.25)	0.3 (1) harbor chop	3.81 (1.5), 40
7	Naphtha	V_c ± (0.25)	no wave	
8	Naphtha	V_c ± (0.25)	0.6 (3), 9.1 (30), 3.0	11.43 (4.5), 40

*Boom performance was observed up to failure and detailed observation was utilized at ±0.25 m/s (0.5 kt) relative to that failure point.

TABLE 4. STATIONARY SKIMMER TEST MATRIX

Test no.	Test fluid	Wave character height m (ft)	Wave generator eccentric cm (in), CPM
1-3	Octanol	no wave	
4-6	Octanol	0.6 (2) harbor chop	7.62 (3.0), 30
7-9	Naphtha	no wave	
10-12	Naphtha	0.6 (2) harbor chop	7.62 (3.0), 30
13-15	DOP	no wave	
16-18	DOP	0.6 harbor chop	7.62 (3.0), 30

Notes:

1. Pump rate set at optimum
2. A 3.0 m^3 volume of HM (800 gal) was distributed within air barrier surface area of 147.6 m^2 (1589 ft^2).
3. Including compressive effects of air barrier on slick size, the effective slick surface area was approximately 100 m^3 (1076 ft^2).

TABLE 5. DIP-1002 ADVANCING SKIMMER TEST MATRIX

Test no.	Test fluid	Fluid distribution rate $m^3/s \times 10^{-3}$ (gal/min)	Tow speed m/s (kt)
1	Octanol	1.93 (30.6)	0.64 (1.25)
2	Octanol	2.32 (36.8)	0.76 (1.50)
3	Octanol	1.55 (24.6)	0.51 (1.00)
4	Octanol	2.71 (43.0)	0.89 (1.75)
5	Octanol	3.09 (49.0)	1.02 (2.00)
6	DOP	1.93 (30.6)	0.64 (1.25)
7	DOP	2.32 (36.8)	0.76 (1.50)
8	DOP	1.55 (24.6)	0.51 (1.00)
9	DOP	2.71 (43.0)	0.89 (1.75)
10	DOP	3.09 (49.0)	1.02 (2.10)
11	Naphtha	1.93 (30.6)	0.64 (1.25)
12	Naphtha	2.32 (36.8)	0.76 (1.50)
13	Naphtha	1.55 (24.6)	0.51 (1.00)
14	Naphtha	2.71 (43.0)	0.89 (1.75)
15	Naphtha	3.09 (49.0)	1.02 (2.00)

Note: All tests in calm water.

TABLE 6. ORS-125 ADVANCING SKIMMER TEST MATRIX

Test no.	Test fluid	Fluid distribution rate $m^3/s \times 10^{-3}$ (gal/min)	Tow speed m/s (kt)
1	Naphtha	1.55 (24.6)	0.25 (0.50)
2	Naphtha	2.32 (36.8)	0.38 (0.75)
3	Naphtha	3.09 (49.0)	0.51 (1.00)
4	Naphtha	3.87 (61.3)	0.64 (1.25)
5	Naphtha	4.64 (73.5)	0.76 (1.50)
6	Octanol	1.55 (24.6)	0.25 (0.50)
7	Octanol	2.32 (36.8)	0.38 (0.75)
8	Octanol	3.09 (49.0)	0.51 (1.00)
9	Octanol	3.87 (61.3)	0.64 (1.25)
10	Octanol	4.64 (73.5)	0.76 (1.50)
11	DOP	1.55 (24.6)	0.25 (0.50)
12	DOP	2.32 (36.8)	0.38 (0.75)
13	DOP	3.09 (49.0)	0.51 (1.00)
14	DOP	3.87 (61.3)	0.64 (1.25)
15	DOP	4.64 (73.5)	0.76 (1.50)

Note: All tests in calm waters.

TABLE 7. SORBENT SYSTEM TEST MATRIX

Test no.	Test fluid	Fluid distribution rate $m^3/s \times 10^{-3}$ (gpm)	Tow speed m/s (ft)	Wave character height m (ft)
1	DOP	2.37 (37.5)	1.02 (2.0)	No wave
2	DOP	2.37 (37.5)	1.02 (2.0)	0.3 (1) harbor chop
3	DOP	2.37 (37.5)	1.02 (2.0)	0.6 (2) harbor chop
4	Octanol	2.37 (37.5)	1.02 (2.0)	No wave
5	Octanol	2.37 (37.5)	1.02 (2.0)	0.3 (1) harbor chop
6	Octanol	2.37 (37.5)	1.02 (2.0)	0.6 (2) harbor chop
7	Naphtha	2.37 (37.5)	1.02 (2.0)	No wave
8	Naphtha	2.37 (37.5)	1.02 (2.0)	0.3 (1) harbor chop
9	Naphtha	2.37 (37.5)	1.02 (2.0)	0.6 (2) harbor chop

SECTION 6

BOOM TESTS

BOOM TOW TEST PROCEDURE

The first step was deployment and rigging of the boom, and connection to the bridge (as shown in Figures 2 and 3). Once the water surface condition was established (wave or no wave), the boom was towed at continuously increasing speed until judged unstable by observation from the traveling truss located behind the boom apex. Then the tow speed was decreased in 3 m/min (0.1 kt) increments until the boom became stable, and then speed was increased in 3 m/min increments to reconfirm the failure speed. This speed was entered as the "critical tow speed". The failure point was also documented via 16 mm movies and 35 mm color slides. Modes of failure were noted.

The tow tests for booms in HM were conducted in a similar manner as the above stability tests. HM were distributed as 2 mm (0.08 in) thick, 15.24 m (50 ft) wide spills amounting to approximately 1.32 m^3 (350 gal). Here, the critical tow speed was defined as the maximum tow speed, for catenary or diversionary configurations, at which there was no loss of HM under the boom (i.e., no shedding). Other modes of HM loss were documented, but not used as the criterion for determining the critical tow speed. The only exception: if a mode of failure, other than shedding, was prevalent at speeds significantly lower than the speed required for shedding, then the critical tow speed was based on that mode of failure. Photographic documentation included 16 mm movies and 35 mm slides, both in color.

For details of the catenary and diversionary test set-up, see Figures 2 and 3. To maintain a smooth diversionary profile against the relative current, a parachute mooring device was employed as shown. The exact lengths of booms tested are given in Appendix C and the test matrices are given in Tables 2 and 3.

A step-by-step test procedure for booms is given below in the following format: Manpower Allocations, Pre-test Checklist, Test Sequence, Data Sheets and Data Analysis.

Manpower Allocations

The following allocations of duties were made:

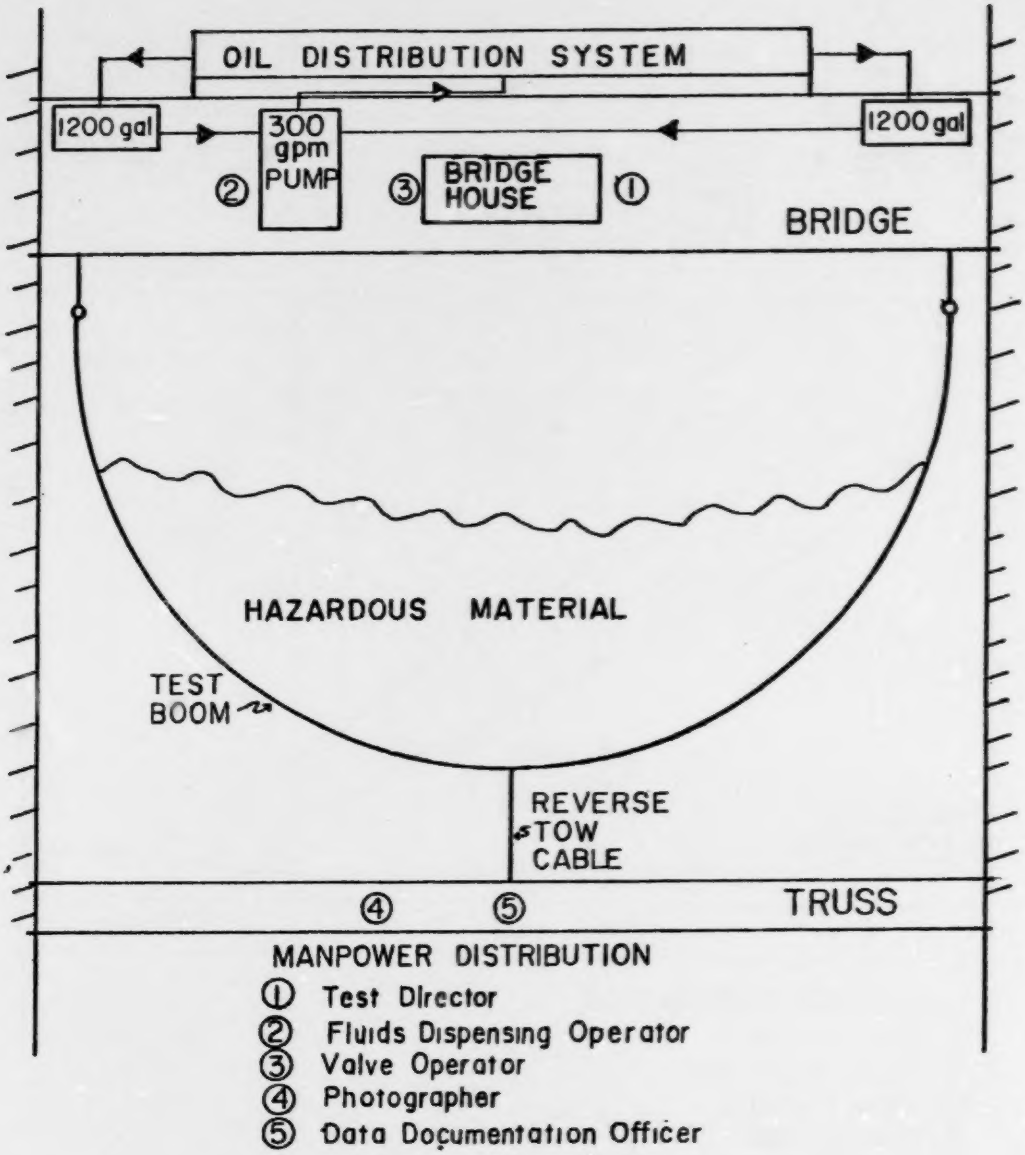

Figure 2. Catenary boom test details.

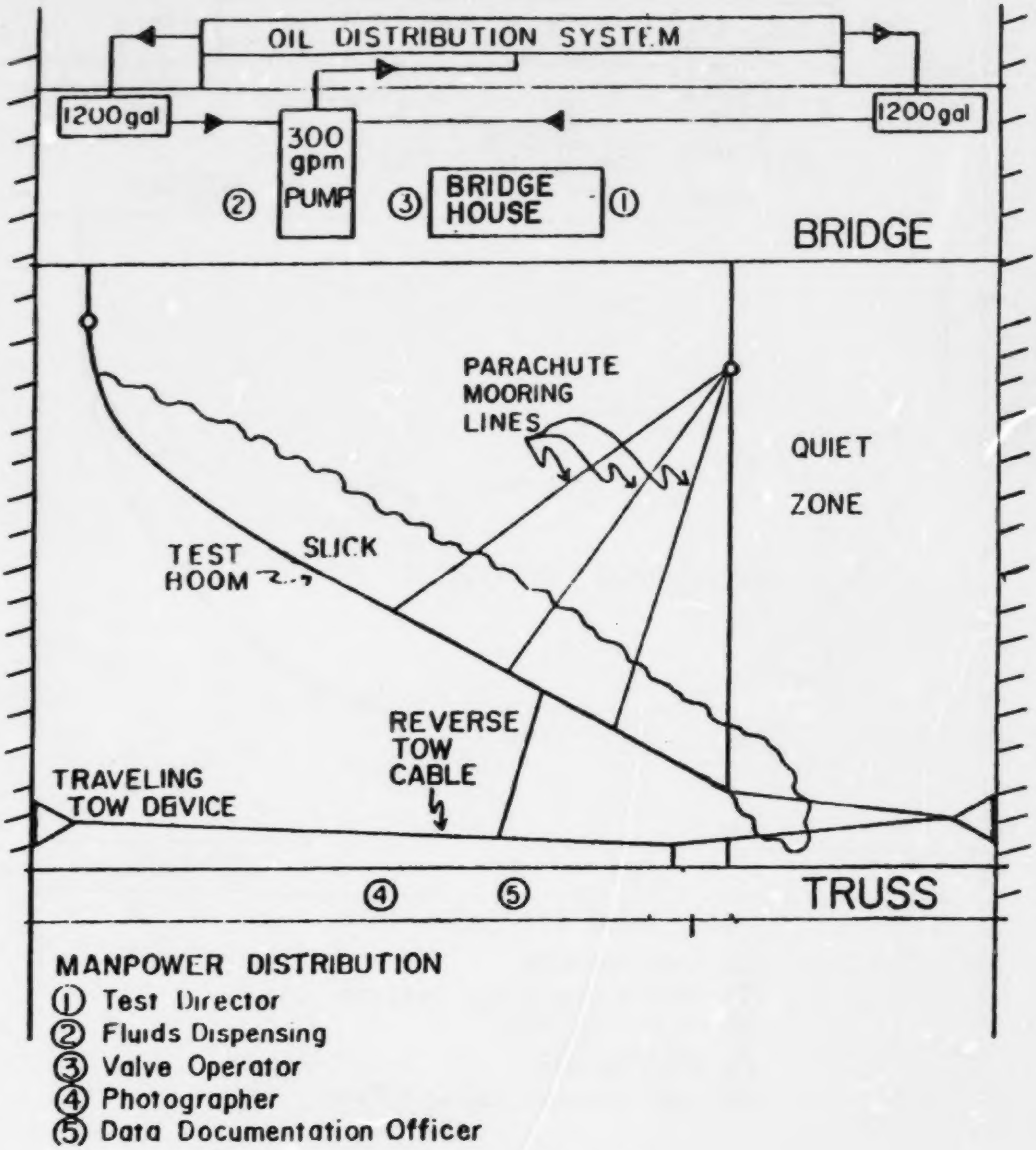

Figure 3. Diversionary test details.

1. Test director - responsible for running the tests according to the prescribed test matrix and test procedure. Manages the test personnel.

2. Control room operator - operates the traveling bridge, wave generator and bubble barrier from the control tower located at the North end of the tank. He also collects the data for ambient conditions.

3. Fluids dispensing operator - usually a temporary technician who adjusts the flow control valves for the proper flow rate and records the flow rate.

4. Data documentation officer - observes and records failure conditions and modes of failure. Communicates with test director and photographer on tow speed changes and documentation of performance. Performs the analysis and reduction of all data.

5. Photographer - photographically documents the test runs with 35 mm color slides, 16 mm color motion pictures, and/or underwater video tape.

6. Chemical analysis officer - takes samples of the test fluid before its distribution and after its recovery for analysis of water content, viscosity, specific gravity and interfacial tension for the test run. In general, analysis of fluids for chemical and physical properties is his responsibility.

7. Valve operator - ususally a temporary technician who operates the pneumatic valve controls for recirculation and distribution of the test fluid.

8. Fluids clean up team leader - heads the operation of cleaning the residual test fluid from the water surface in preparation for the next test run.

9. Fluids refurbishment team leader - heads the operation of removing water (both free and emulsified) and contaminants from the test fluid prior to its reuse. Also, responsible for operating the filter unit to maintain water purity and clarity.

10. Other temporary aides were positioned as required.

Pre-test Checklist

To ensure that all systems and equipment were maintained and ready for the test, the following checklist was used prior to the first test run:

1. D.E. filter system operating
2. Chlorine generator operating
3. Air-bubble barrier system operating

4. Bridge drive system operating
5. Wave generator system operational
6. Test device operational
7. Test instrumentation operational
8. Test fluid ready
9. Test fluid distribution system operational
10. Test support equipment operational
11. Photographic systems ready
12. Test personnel prepared and ready
13. Complete all pre-run data sheets and checklists

Test Sequence (with test fluid)

The following test sequence was used for the catenary and diversionary boom tests:

1. Position the traveling bridge and test device for testing (see Figures 2 and 3).

2. Position all test personnel for testing (see Figures 2 and 3).

3. Inform all test personnel of test conditions taken from the test matrix.

4. Calibrate the flow rate using the recirculation mode, and continue to recirculate while observing test fluid temperature and pressure drop. Just prior to test run, take samples of recirculating test fluid and record test fluid temperature.

5. Give three (3) blasts on the air horn to clear the tank decks, alert all test personnel of test run, and start wave generator, if required.

6. Using either intercom system of walkie-talkies, begin countdown from five (5), with the control room operator to begin bridge motion at zero (0) and one (1) blast on the air horn.

7. One (1) blast on the air horn initiates the following: start bridge, start test fluid distribution, and start stopwatches.

8. Control room operator informs test director of steady state bridge speed.

9. Data documentation officer informs test director of boom performance and advises him of speed increases and/or decreases. Photographic documentation occurs simultaneously.

10. Test fluid distribution ceases after 1.3 m^3 (350 gal) is distributed, and distribution time is recorded.

11. Define the boom "no test fluid loss" speed and modes of failure.

12. Test director begins countdown from five (5) to stop the bridge, the wave generator and stopwatches.

13. Lower the bridge "skimming plate" to prevent test fluid from passing under the bridge and to skim all residual test fluid back to the north end of the tank into the surface containment area.

14. All boom data sheets are completed and the integrated skimmer tests begin if required.

15. Reverse the bridge and test boom to prepare for the next test run.

16. Stability tests would follow this same procedure without the test fluid being distributed.

Data Sheets

The following data sheets were used for the boom tests:

1. Test Equipment Characteristics
2. Chemistry Laboratory Analysis
3. Flow Rate/Volume Data Sheet
4. Ambient Conditions Data Sheet
5. Boom Test Data Sheet

Data Analysis

The data documentation officer performs all data analysis and reduction. All data sheets are submitted to him for compilation onto master raw data sheets as shown in Tables 8, 9, and 10. The ultimate responsibility for proper data collection, analysis and presentation belongs to the OHMSETT Project Engineer. He writes the final report and disseminates data to the EPA Project Officer.

TEST DATA

The following test result tables contain information on the test fluid properties, ambient conditions and wave characteristics at the time the boom was tested. The critical tow speed column lists the maximum speed at which the boom can be towed before either losing HM under the skirt or becoming unstable. The codes for the different modes of boom bailure are as follows:

SU - submarining

SH - shedding

SP - splashover

WA - washover

PL - planing

TABLE 10. TEST RESULTS U.S. COAST GUARD PROTOTYPE HIGH SEAS BOOM

			TEST FLUIDS PROPERTIES						AMBIENT CONDITIONS			SLICK CHARACTERISTICS						WAVE CHARACTERISTICS				PERFORMANCE CHARACTERISTICS		
DATE	TIME	TEST NUMBER	TYPE	TEMPERATURE °C	VISCOSITY m^2/sec. x 10^{-6}	SURFACE TENSION N/m x 10^{-3}	INTERFACIAL N/m x 10^{-3}	SPECIFIC GRAVITY	AIR TEMPERATURE °C	WIND SPEED m/sec.	WIND DIRECTION	DISTRIBUTION VOLUME m^3				TOW SPEED RANGE m/sec.		HEIGHT meters	LENGTH meters	PERIOD sec.		CRITICAL TOW SPEED m/sec.	MODE OF FAILURE	
												CATENARY												
10/20	0900	S-1							14.4	4.5	E					0 -	.76	0	0			.51	SU	
10/20	0915	S-2							14.4	4.5	E					0 -	.51	0.6	9.1	3.0		.18 (.43)	SP (SU)	
10/20	0940	7	NAP	14.4	6.5	23.6	14.7	.7815	14.4	4.5	NE	1.32				0 -	.51	0	0			.46	WA	
10/20	1030	7R	NAP	14.4	6.5	23.6	14.7	.7815	14.4	5.4	NE	1.32				0 -	.51	0	0			.46	WA	
10/20	1055	8	NAP	14.4	6.5	23.6	14.7	.7815	15.0	6.7	NE	1.32				0 -	.51	0.6	9.1	3.0		.20	WA	
10/20	1125	$7R^2$	NAP	14.4	6.5	23.6	14.7	.7815	15.0	4.5	NE	1.32				0 -	.51	0	0			.46	WA	
10/20	1330	S-3							15.0	3.6	NE					0 -	.51	0.3	HC			.46	SU	
10/20	1330	6	NAP	14.4	6.5	23.6	14.7	.7815	15.0	3.6	NE	1.32				0 -	.51	0.3	HC			.05	WA	
10/21	1000	4	OCT	15.6	13.7	26.3	8.7	.8585	13.3	4.5	SW	1.32				0 -	.63	0	0			.20 (.51)	SH (WA)	
10/21	1040	4R	OCT	15.6	13.7	26.3	8.7	.8585	15.0	4.5	SW	1.32				0 -	.63	0	0			.20	SH	
10/21	1110	$4R^2$	OCT	15.6	13.7	26.3	8.7	.8585	16.1	4.5	SW	1.32				0 -	.63	0	0			.20	SH	

TABLE 9. (Continued)

			TEST FLUIDS PROPERTIES						AMBIENT CONDITIONS			SLICK CHARACTERISTICS						WAVE CHARACTERISTICS				PERFORMANCE CHARACTERISTICS		
DATE	TIME	TEST NUMBER	TYPE	TEMPERATURE °C	VISCOSITY m^2/sec. x 10^{-6}	SURFACE TENSION N/m x 10-3	INTERFACIAL N/m x 10-3	SPECIFIC GRAVITY	AIR TEMPERATURE °C	WIND SPEED m/sec.	WIND DIRECTION	DISTRIBUTION VOLUME m^3				TOW SPEED RANGE m/sec.		HEIGHT meters	LENGTH meters	PERIOD sec.		CRITICAL TOW SPEED m/sec.	MODE OF FAILURE	
										CATENARY														
10/21	1120	3	OCT	15.6	13.7	26.3	8.7	.8585	16.1	4.5	SW	1.32				0 - .63		0.6	9.1	3.0		.20	SH	
10/21	1340	1	DOP	15.0	74.9	28.8	15.0	.9785	18.9	2.2	SW	1.32				0 - .25		0	0			.10	SH	
10/21	1420	1R	DOP	15.0	74.9	28.8	15.0	.9785	19.4	6.7	SW	1.32				0 - .25		0	0			.10	SH	
10/21	1440	2	DOP	15.0	74.9	28.8	15.0	.9785	20.6	6.7	SW	1.32				0 - .25		0.6	9.1	3.0		.15 (.23)	SP (SH)	
										DIVERSIONARY														
10/23	0915	S-1							17.8	2.2	E					0 - .76		0	0			.63	SU	
10/23	0940	S-2							17.8	2.2	E					0 - .76		0.6	9.1	3.0		.38 (.56)	SP (SU)	
10/23	1012	1	DOP	15.0	74.9	28.8	15.0	.9785	17.8	2.2	E	1.32				0 - .38		0	0			.13	SH	
10/23	1033	2	DOP	15.0	74.9	28.8	15.0	.9785	17.8	2.7	NE	1.32				0 - .25		0.6	9.1	3.0		.08 (.05)	SP (SH)	
10/23	1055	1R	DOP	15.0	74.9	28.8	15.0	.9785	17.8	3.1	NE	1.32				0 - .76		0	0			.15 (.63)	SH (SU)	

TABLE 9. (Continued)

			TEST FLUIDS PROPERTIES						AMBIENT CONDITIONS			SLICK CHARACTERISTICS						WAVE CHARACTERISTICS				PERFORMANCE CHARACTERISTICS		
DATE	TIME	TEST NUMBER	TYPE	TEMPERATURE °C	VISCOSITY m^2/sec. x 10^{-6}	SURFACE TENSION N/m x 10-3	INTERFACIAL N/m x 10-3	SPECIFIC GRAVITY	AIR TEMPERATURE °C	WIND SPEED m/sec.	WIND DIRECTION	DISTRIBUTION VOLUME m^3				TOW SPEED RANGE m/sec.		HEIGHT meters	LENGTH meters	PERIOD sec.		CRITICAL TOW SPEED m/sec.	MODE OF FAILURE	
										DIVERSIONARY														
10/23	1335	4	OCT	15.6	13.3	27.6	8.5	.8580	18.9	3.6	E	1.32				0 - .51		0	0			.36	SH	
10/23	1352	4R	OCT	15.6	13.3	27.6	8.5	.8580	18.9	3.6	NE	1.32				0 - .51		0	0			.36	SH	
10/23	1410	4R^2	OCT	15.6	13.3	27.6	8.5	.8580	18.9	3.1	NE	1.32				0 - .51		0	0			.36	SH	
10/23	1427	3	OCT	15.6	13.3	27.6	8.5	.8580	18.9	3.6	NE	1.32				0 - .38		0.6	9.1	3.0		.13	SP	
10/24	0855	7	NAP	16.1	7.1	24.0	13.9	.7965	16.7	2.2	SW	1.32				0 - .76		0	0			.56	SH SP	
10/24	0915	7R	NAP	16.1	7.1	24.0	13.9	.7965	17.2	3.1	SW	1.32				0 - .76		0	0			.56	SH SP	
10/24	0935	7R^2	NAP	16.1	7.1	24.0	13.9	.7965	17.8	3.1	NW	1.32				0 - .76		0	0			.51	SH	
10/24	0945	8	NAP	16.1	7.1	24.0	13.9	.7965	17.8	3.1	NW	1.32				0 - .63		0.6	9.1	3.0		.46	SP	
10/24	1125	S-3							20.0	2.2	NE					0 - .25		0.3	HC			0 (.15)	SP (SU)	
10/24	1125	6	NAP	16.1	7.1	24.0	13.9	.7965	20.0	2.2	NE	1.32				0 - .25		0.3	HC			0	SP	

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TABLE 9. TEST RESULTS B.F. GOODRICH BOOM

			TEST FLUIDS PROPERTIES						AMBIENT CONDITIONS			SLICK CHARACTERISTICS					WAVE CHARACTERISTICS				PERFORMANCE CHARACTERISTICS		
DATE	TIME	TEST NUMBER	TYPE	TEMPERATURE °C	VISCOSITY m^2/sec. x 10-6	SURFACE TENSION N/m x 10-3	INTERFACIAL N/m x 10-3	SPECIFIC GRAVITY	AIR TEMPERATURE °C	WIND SPEED m/sec.	WIND DIRECTION	DISTRIBUTION VOLUME m^3				TOW SPEED RANGE m/sec.	HEIGHT meters	LENGTH meters	PERIOD sec.		CRITICAL TOW SPEED m/sec.	MODE OF FAILURE	
										CATENARY													
10/9	1015	S-1							17.2	6.7	NE					0 - 1.27	0	0			1.02	PL	
10/9	1045	S-2							17.2	8.0	NE					0 - .51	0.6	HC			0	SP	
10/9	1130	S-3							17.2	6.7	NE					0 - 1.02	0.3	HC			.38 (.86)	SP (PL)	
10/9	1355	3	OCT	16.7	14.0	26.2	7.8	.8475	16.1	7.2	NE	1.32				0 - .36	0	0			.25	SH	
10/9	1425	4	OCT	16.7	14.0	26.2	7.8	.8475	15.6	8.9	NE	1.32				0 - .25	0.3	HC			0	SP	
10/9	1510	3R	OCT	16.7	14.0	26.2	7.8	.8475	15.0	7.4	NE	1.32				0 - .25	0	0			.25	SH	
10/9	1520	S-4							14.4	6.7	NE					0 - .81	0.6	9.1	3.0		.76	PL	
10/10	1250	5	OCT	15.0	14.2	25.6	8.0	.8485	16.7	4.5	NE	1.32				0 - .30	0.6	9.1	3.0		.25	SH	
10/10	1455	1	DOP	15.6	79.2	29.2	15.8	.9770	16.7	2.7	NE	1.32				0 - .15	0	0			.10	SH	
10/10	1525	2	DOP	15.6	79.2	29.2	15.8	.9770	16.7	3.6	NE	1.32				0 - .25	0.6	9.1	3.0		0	SP	
10/14	0950	7	NAP	16.7	6.5	23.2	30.4	.7730	20.0	4.5	SW	1.32				0 - .63	0	0			.46	SH	

(Continued)

TABLE 8. (Continued)

DATE	TIME	TEST NUMBER	TEST FLUIDS PROPERTIES						AMBIENT CONDITIONS			SLICK CHARACTERISTICS				TOW SPEED RANGE m/sec.	WAVE CHARACTERISTICS				PERFORMANCE CHARACTERISTICS		
			TYPE	TEMPERATURE °C	VISCOSITY m^2/sec. x 10^{-6}	SURFACE TENSION N/m x 10^{-3}	INTERFACIAL N/m x 10^{-3}	SPECIFIC GRAVITY	AIR TEMPERATURE °C	WIND SPEED m/sec.	WIND DIRECTION	DISTRIBUTION VOLUME m^3					HEIGHT meters	LENGTH meters	PERIOD sec.		CRITICAL TOW SPEED m/sec.	MODE OF FAILURE	
CATENARY																							
10/14	1020	7R	NAP	16.7	6.5	23.2	30.4	.7730	20.0	4.5	SW	1.32				0 - .63	0	0			.46	SH	
10/14	1105	8	NAP	16.7	6.5	23.2	30.4	.7730	23.3	4.5	SW	1.32				0 - .63	0.6	9.1	3		0 (.41)	SP (SH)	
10/14	1140	8R	NAP	16.7	6.5	23.2	30.4	.7730	24.4	4.0	SW	1.32				0 - .63	0.6	9.1	3		0 (.41)	SP (SH)	
DIVERSIONARY																							
10/15	1000	S-1							24.4	1.3	NW					0 - 1.14	0	0			.97	PL	
10/15	1025	4	OCT	17.8	13.4	26.5	8.7	.8565	24.4	1.3	NW	1.32				0 - 1.02	0	0			.76	SH	
10/15	1320	4R	OCT	17.8	13.4	26.5	8.7	.8565	28.9	2.2	W	1.32				0 - 1.02	0	0			.86	SH	
10/15	1340	$4R^2$	OCT	17.8	13.4	26.5	8.7	.8565	30.0	4.5	W	1.32				0 - 1.02	0	0			.76	SH	
10/15	1420	S-2							29.4	4.5	SW					0 - 1.27	0.6	9.1	3.0		.15 (.97)	SP (SU)	
10/15	1440	3	OCT	17.8	13.4	26.5	8.7	.8565	29.4	4.5	SW	1.32				0 - .51	0.6	9.1	3.0		.15 (.46)	SP (SH)	

TABLE 8. (Continued)

DATE	TIME	TEST NUMBER	TEST FLUIDS PROPERTIES						AMBIENT CONDITIONS			SLICK CHARACTERISTICS						WAVE CHARACTERISTICS				PERFORMANCE CHARACTERISTICS		
			TYPE	TEMPERATURE °C	VISCOSITY m^2/sec. x 10^{-6}	SURFACE TENSION N/m x 10^{-3}	INTERFACIAL N/m x 10^{-3}	SPECIFIC GRAVITY	AIR TEMPERATURE °C	WIND SPEED m/sec.	WIND DIRECTION	DISTRIBUTION VOLUME m^3				TOW SPEED RANGE m/sec.		HEIGHT meters	LENGTH meters	PERIOD sec.		CRITICAL TOW SPEED m/sec.	MODE OF FAILURE	
										DIVERSIONARY														
10/16	0850	S-3							20.0	5.4	SW					0 - 1.02		0.3	HC			0 (1.02)	SP (SU)	
10/16	1140	1	DOP	17.8	72.3	28.4	15.2	.9805	21.1	4.5	SW	1.32				0 - .51		0	0			.15	SH	
10/16	1310	2	DOP	17.8	72.3	28.4	15.2	.9805	23.3	4.5	SW	1.32				0 - .25		0.6	9.1	3.0		.05 (.05)	SP (SH)	
10/16	1320	1R	DOP	17.8	72.3	28.4	15.2	.9805	23.3	3.6	SW	1.32				0 - .51		0	0			.15	SH	
10/16	1335	7	NAP	15.6	7.3	24.1	10.8	.8015	23.9	3.6	SW	1.32				0 - 1.02		0	0			.81	SH	
10/17	0915	7R	NAP	15.6	7.3	24.1	10.8	.8015	14.4	6.7	E	1.32				0 - 1.02		0	0			.81	SH	
10/17	0935	7R^2	NAP	15.6	7.3	24.1	10.8	.8015	14.4	5.4	NE	1.32				0 - 1.02		0	0			.81	SH	
10/17	1005	8	NAP	15.6	7.3	24.1	10.8	.8015	14.4	4.5	NE	1.32				0 - 1.02		0.6	9.1	3.0		.20 (.63)	SP (SH)	

(Continued)

TABLE 8. TEST RESULTS CLEAN WATER BOOM

			TEST FLUIDS PROPERTIES						AMBIENT CONDITIONS			SLICK CHARACTERISTICS						WAVE CHARACTERISTICS				PERFORMANCE CHARACT.		
DATE	TIME	TEST NUMBER	TYPE	TEMPERATURE °C	VISCOSITY m^2/sec. x 10^{-6}	SURFACE TENSION N/m x 10-3	INTERFACIAL N/m x 10-3	SPECIFIC GRAVITY	AIR TEMPERATURE °C	WIND SPEED m/sec.	WIND DIRECTION	DISTRIBUTION VOLUME m^3				TOW SPEED RANGE m/sec.		HEIGHT meters	LENGTH meters	PERIOD sec.		CRITICAL TOW SPEED m/sec.	MODE OF FAILURE	
										CATENARY														
10/28	1620	S-1							18.9	2.2	W					0 -	1.02	0	0			.89	PL	
10/29	0900	7	NAP	15.0	7.0	23.5	11.1	.7965	15.6	2.7	SW	1.32				0 -	.51	0	0			.46	SH	
10/29	0930	6	NAP	15.0	7.0	23.5	11.1	.7965	17.2	2.2	SW	1.32				0 -	.76	0.3	HC			.38 (.36)	SP (SH)	
10/29	1007	ST-1							17.8	2.7	S					0 -	.51	0.6	HC			.36	SP	
10/29	1130	8	NAP	15.0	7.0	23.5	11.1	.7965	18.9	2.7	SW	1.32				0 -	.38	0.6	9.1	3.0		.30	SH	
10/29	1205	7R	NAP	15.0	7.0	23.5	11.1	.7965	19.4	2.7	S	1.32				0 -	.63	0	0			.46	SH	
10/31	0930	3	OCT	15.0	13.6	26.0	7.5	.8715	17.2	2.2	S	1.32				0 -	.51	0	0			.38	SH	
10/31	0955	4	OCT	15.0	13.6	26.0	7.5	.8715	17.2	2.4	SW	1.32				0 -	.38	0.6	9.1	3.0		.15	SH	
10/31	1335	1	DOP	13.9	80.1	29.1	14.7	.9815	19.6	2.7	W	1.32				0 -	.25	0	0			.13	SH	
10/31	1410	2	DOP	13.9	80.1	29.1	14.7	.9815	18.8	2.2	W	1.32				0 -	.51	0.6	9.1	3.0		.10	SH	

(Continued)

BOOM TEST RESULTS - DISCUSSION

The performance parameters measured for both diversionary and catenary testing of booms were critical tow speeds for boom stability, HM containment and HM diversion, and modes of failure. Critical tow speed refers to the speed at which either the boom fails (boom stability) or the HM slick cannot be controlled by the boom (HM slick stability). Therefore, even though a boom performs perfectly in 0.6 m (2 ft) waves at 1.0 m/s (2 kt) tow speeds without the slick present, hydrodynamic mechanisms (entrainment, splashing waves and vortices) prevent the boom from controlling a slick under these conditions. As indicated by the results of this test project, physical properties of the slick and hydrodynamic (water surface and currents) conditions ultimately determine the maximum tow speed at which the boom controls the slick.

Stability tests were first run with each boom system to determine operational limitations in terms of tow speeds and wave characteristics. Using 0.25 m/s (0.5 kt) as the minimum speed considered for operations, only the Coast Guard Prototype High Seas Boom performed successfully in the 0.6 m (2.0 ft) harbor chop (H.C.) wave at 0.36 m/s (0.7 kt), before water splashover became significant. Thus, the 0.6 m H.C. was considered the upper limit wave condition tested; followed closely by the 0.3 m (1.0 ft) H.C. which also caused boom performance to drop sharply. For all booms tested, performance deteriorated gradually from calm water conditions, 0.6 m x 9.1 m x 3.0 s waves, 0.3 m H.C. and 0.6 m H.C. waves. In some cases, 0.6 m H.C. tests were omitted after it became obvious that this wave was beyond the operability range of the boom. Maximum critical tow speeds attained in the diversionary and catenary modes under calm water and 0.6 m x 9.1 m x 3.0 s wave conditions are given in Tables 11, 12, 13, and 14 for the Cleanwater and B.F. Goodrich booms. These tables also include comparative results of an earlier test project (5).

Critical tow speeds for tests with Naphtha, octanol, and DOP slicks and in wave conditions described above, were lower than stability speeds due to the following modes of failure:

- Shedding--droplet formation at the HM/water interface and entrainment of droplets swept under the boom.
- Splashover--HM periodically being heaved by waves over the boom freeboard.
- Washover--large amounts of HM heaved by waves over the boom combined with loss of freeboard due to partial submergence of boom.

Critical tow speeds depended very much on the test fluid physical properties as shown in Tables 11, 12, 13, and 14. Specific gravity appeared to be the predominate independent variable even though a strict testing of each property was not accomplished. Generally, critical tow speed decreased as specific gravity increased going from Naphtha with the lowest (≈ 0.977). DOP was not adequately controlled by any of the booms tested at tow speeds above 0.15 m/s (0.3 kt) in the waves tested nor in calm water. Therefore, according to these tests, spill material of high specific gravity (≈ 1.0) cannot be controlled with present day conventional booms in currents ≥ 0.15 m/s (0.3 kt).

TABLE 11. CLEANWATER BOOM PERFORMANCE (CATENARY CONFIGURATION)

TEST NUMBER	TEST FLUID	WAVE CONDITION H x L x p	CRITICAL TOW SPEED (m/s)	TEST FLUID PROPERTIES					MODE OF FAILURE
				Temperature °C	Viscosity x $10^{-6}m^2/s$	Surface Tension x $10^{-3}N/m$	Interfacial x $10^{-3}N/m$	Specific Gravity	
1.	STABILITY	NO WAVE	0.60						SUBMARINING
	(NO OIL)	0.6 m x 9.14 m x 3 s	0.25						SPLASHOVER
2.	LUBE OIL	NO WAVE	0.51	26.0	405	31.7		0.915	SHEDDING
		0.6 m x 9.14 m x 3 s	0.25	30.0	345	34.7		0.915	SPLASHOVER
3.	STABILITY	NO WAVE	0.51						SUBMARINING
	(NO HM)	0.6 m x 9.14 m x 3 s	0.17 (0.43)						SPLASHOVER (SUBMARINING)
4.	DOP	NO WAVE	0.10	15.0	74.9	28.8	15.0	0.978	SHEDDING
		0.6 m x 9.14 m x 3 s	0.15 (0.23)	15.0	74.9	28.8	15.0	0.978	SPLASHOVER (SHEDDING)
5.	OCTANOL	NO WAVE	0.20	15.6	13.7	26.3	8.7	0.858	SHEDDING
		0.6 m x 9.14 m x 3 s	0.20	15.6	13.7	26.3	8.7	0.858	SHEDDING
6.	NAPHTHA	NO WAVE	0.45	14.4	6.5	23.6	14.7	0.781	WASHOVER
		0.6 m x 9.14 m x 3 s	0.20	14.4	6.5	23.6	14.7	0.781	WASHOVER

NOTE: Test numbers 1 and 2 are results taken from an earlier boom test project (JO-6) in Reference 5.

TABLE 12. CLEANWATER BOOM PERFORMANCE (DIVERSIONARY CONFIGURATION)

TEST NUMBER	TEST FLUID	WAVE CONDITION H x L x p	CRITICAL TOW SPEED (m/s)	TEST FLUID PROPERTIES					MODE OF FAILURE
				Temperature ^{o}C	Viscosity x 10^{-6}m^2/s	Surface Tension x 10^{-3}N/m	Interfacial x 10^{-3}N/m	Specific Gravity	
1.	STABILITY (NO OIL)	NO WAVE	0.78						SUBMARINING
		0.6 m x 9.1 m x 3 s	0.45						SUBMARINING
2.	LUBE OIL	NO WAVE	0.61	20.0	1718	32.4		0.915	SHEDDING
		0.6 m x 9.1 m x 3 s	0.41	20.0	1068	33.6		0.915	SHEDDING
3.	STABILITY (NO HM)	NO WAVE	0.63						SUBMARINING
		0.6 m x 9.1 m x 3 s	0.55 (0.38)						SUBMARINING (SPLASHOVER)
4.	DOP	NO WAVE	0.12	15.0	74.9	28.8	15.0	0.978	SHEDDING
		0.6 m x 9.1 m x 3 s	0.07	15.0	74.9	28.8	15.0	0.978	SPLASHOVER
5.	OCTANOL	NO WAVE	0.35	15.6	13.3	27.6	8.5	0.858	SHEDDING
		0.6 m x 9.1 m x 3 s	0.12	15.6	13.3	27.6	8.5	0.858	SPLASHOVER
6.	NAPHTHA	NO WAVE	0.55	16.1	7.1	24.0	13.9	0.796	SHEDDING
		0.6 m x 9.1 m x 3 s	0.45	16.1	7.1	24.0	13.9	0.796	SPLASHOVER

NOTE: Test numbers 1 and 2 are results taken from an earlier boom test project JO-6 in Reference 5.

TABLE 13. B.F. GOODRICH BOOM PERFORMANCE (CATENARY CONFIGURATION)

TEST NUMBER	TEST FLUID	WAVE CONDITION H x L x p	CRITICAL TOW SPEED (m/s)	TEST FLUID PROPERTIES					MODE OF FAILURE
				Temperature ^{o}C	Viscosity x $10^{-6}m^2/s$	Surface Tension x $10^{-3}N/m$	Interfacial x $10^{-3}N/m$	Specific Gravity	
1.	STABILITY	NO WAVE	1.27						SPLASHOVER
	(NO OIL)	0.6 m x 9.1 m x 3 s	0.73						SPLASHOVER
2.	LUBE OIL	NO WAVE	0.43	37.0	381	31.5		0.915	SHEDDING
		0.6 m x 9.1 m x 3 s	0.45	33.0	381	31.5		0.915	SHEDDING
3.	STABILITY	NO WAVE	1.01						PLANING
	(NO HM)	0.6 m x 9.1 m x 3 s	0.76						PLANING
4.	DOP	NO WAVE	0.10	15.6	79.2	29.2	15.8	0.977	SHEDDING
		0.6 m x 9.1 m x 3 s	0.00	15.6	79.2	29.2	15.8	0.977	SPLASHOVER
5.	OCTANOL	NO WAVE	0.25	16.7	14.0	26.2	7.8	0.847	SHEDDING
		0.6 m x 9.1 m x 3 s	0.25	15.0	14.2	25.6	8.0	0.848	SPLASHOVER
6.	NAPHTHA	NO WAVE	0.45	16.7	6.5	23.2	30.4	0.773	SHEDDING
		0.6 m x 9.1 m x 3 s	0.40	16.7	6.5	23.2	30.4	0.733	SHEDDING

NOTE: Test numbers 1 and 2 are results taken from an earlier boom test project (JO-6) in Reference 5.

TABLE 14. B.F. GOODRICH BOOM PERFORMANCE (DIVERSIONARY CONFIGURATION)

TEST NUMBER	TEST FLUID	WAVE CONDITION H x L x p	CRITICAL TOW SPEED (m/s)	TEST FLUID PROPERTIES					MODE OF FAILURE
				Temperature °C	Viscosity x $10^{-6}m^2/s$	Surface Tension x $10^{-3}N/m$	Interfacial x $10^{-3}N/m$	Specific Gravity	
1.	STABILITY	NO WAVE	0.83						PLANING
	(NO OIL)	0.6 m x 9.1 m x 3 s	0.53						SPLASHOVER
2.	LUBE OIL	NO WAVE	0.61	24.0	267	29.0		0.915	SHEDDING
		0.6 m x 9.1 m x 3 s	0.51	28.0	124	28.8		0.915	SHEDDING
3.	STABILITY	NO WAVE	0.96						PLANING
	(NO HM)	0.6 m x 9.1 m x 3 s	0.15 (0.96)						SPLASHOVER (PLANING)
4.	DOP	NO WAVE	0.15	17.8	72.3	28.4	15.2	0.980	SHEDDING
		0.6 m x 9.1 m x 3 s	0.05 (0.05)	17.8	72.3	28.4	15.2	0.980	SHEDDING (SPLASHOVER)
5.	OCTANOL	NO WAVE	0.76	17.8	13.4	26.5	8.7	0.856	SHEDDING
		0.6 m x 9.1 m x 3 s	0.45 (0.15)	17.8	13.4	26.5	8.7	0.856	SHEDDING (SPLASHOVER)
6.	NAPHTHA	NO WAVE	0.81	15.6	7.3	24.1	10.8	0.801	SHEDDING
		0.6 m x 9.1 m x 3 s	0.63 (0.20)	15.6	7.3	24.1	10.8	0.801	SHEDDING (SPLASHOVER)

Note: Test numbers 1 and 2 are results taken from an earlier boom test project (JO-6) in Reference 5.

SECTION 7

STATIONARY SKIMMER TESTS

STATIONARY SKIMMER TEST PROCEDURES

Stationary skimmer tests were conducted at the north end of the test tank in a 147.6 m^2 (1589 ft^2) surface containment area defined by air barrier lines across the tank and along the tank walls (Figure 4). The test matrix is given in Table 3.

For these tests, 3.02 m^3 (800 gal) of HM was distributed into the surface containment area (Figure 4) to maintain a slick thickness of about 2.0 cm (0.78 in). The skimmer test run began by starting the pump and skimming operation. There was a connection hose from the skimmer head to the pump, and a discharge hose from the pump to the recovery tanks. When recovered fluid was observed at the discharge end of the latter hose, a stopwatch was started to measure the recovery rate. Eighteen 1.89 m^3 (500 gal) polyethylene tanks were used to contain the recovered mixture. The tanks were translucent so that periodic determinations of recovery rate could be made. The skimmer was operated until 1.13 m^3 (200 gal) of HM was removed from the test area, and the time and total volume of recovered fluids were noted. The tank was then replenished with HM to bring the HM volume again up to 3.02 m^3 (800 gal) for the next test.

By measuring the total volume of the recovered HM/water mixture, and the duration of the test run, total recovery rate was measured, for checking against the periodic determinations. After allowing the water to settle out of the HM gravitationally for a minimum of 1/2 h, the volume of water in the recovered mixture was read through the translucent tanks. The percent of recovered HM was calculated and documented as recovery efficiency. HM recovery rate was then calculated by simply multiplying the total recovery rate by the HM recovery efficiency.

Skimmer tests were documented photographically with 16 mm color movies and 35 mm color slides.

A step-by-step test procedure for stationary skimmers is given below in the following format: Manpower Allocations, Pre-test Checklist, Test Sequence, Data Sheets, and Data Analysis.

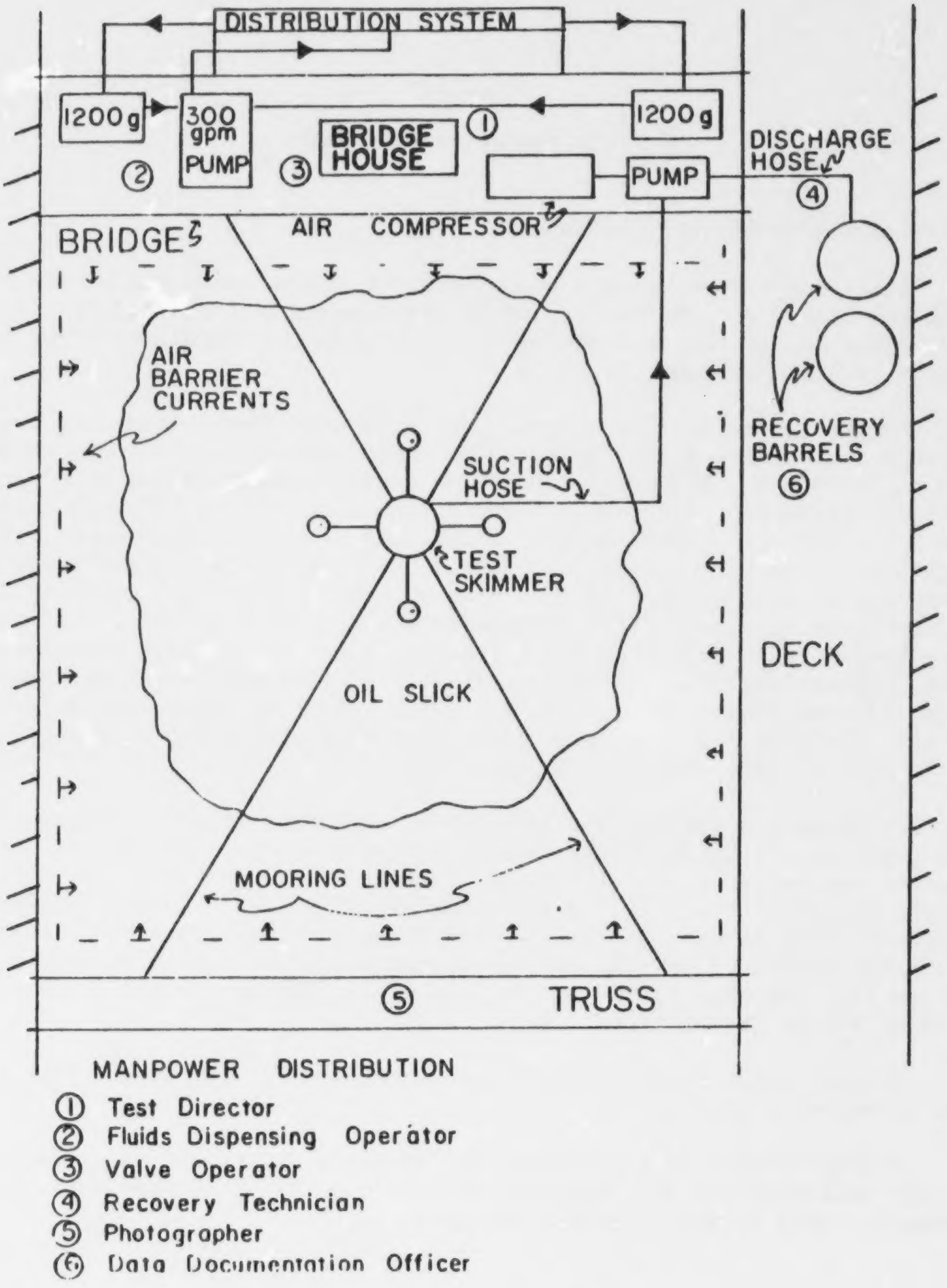

Figure 4. Stationary skimmer test details.

Manpower Allocations

The following allocations of duties were made:

1. Test director - responsible for running the tests according to the prescribed test matrix and test procedure. Manages the test personnel.

2. Control room operator - operates the wave generator and collects the data for ambient conditions.

3. Fluids dispensing operator - maintains the desired fluid thickness at the beginning of each run. Assists with other duties as needed.

4. Data documentation officer - observes and records test fluid collection data and keeps a notebook of performance observations. Performs the analysis and reduction of all data.

5. Photographer - documents the test with 35 mm color slides and 16 mm color motion pictures.

6. Chemical analysis officer - samples the test fluid before and after test run. Samples are analyzed for water content, viscosity, specific gravity and interfacial tension.

7. Test equipment operator - starts the recovery pump and operates the equipment according to manufacturer's recommendations.

8. Fluids refurbishment team leader - heads the operation of removing water and contaminants from the test fluid prior to its reuse.

Pre-test Checklist

To ensure that all test systems and equipment are maintained and ready for the test, the following checklist is used prior to the first test run:

1. D.E. Filter system running
2. Chlorine generator operating
3. Air-bubbler barrier operating
4. Wave generator system operational
5. Test device operational
6. Test fluid ready
7. Test support equipment operational
8. Photographic systems ready
9. Test personnel prepared and ready
10. Complete all pre-run data sheets and checklists

Test Sequence

The following test sequence was used for the stationary skimmer tests:

1. Establish thickened spill condition of 800 gal.

2. Place skimmer system in operating position for the test run.

3. Establish wave conditions according to the test matrix.

4. Place and maintain the recovery hose in the polyethylene recovery tanks.

5. Start the skimmer system with controls set for optimum recovery conditions.

6. Start the stopwatch when recovered fluid begins discharging into the recovery tanks.

7. Check the recovery rate intermittently and photograph the test run.

8. Terminate test run when either 1.89 m^3 (500 gal) is recovered or 30 min of test time elapses.

9. Measure the total recovered fluid, recovery time and temperature of the test fluid.

10. Measure the collected test fluid after allowing the water to settle for at least 1/2 h.

11. Take sample of test fluid layer for analysis.

12. Replenish removed test fluid onto surface in containment area.

13. Prepare for the next test listed in the test matrix.

Data Sheets

The following data sheets were used for the skimmer tests:

1. Test Equipment Characteristics
2. Chemistry Laboratory Analysis
3. Ambient Conditions Data Sheet
4. Skimmer Test Data Sheet

Data Analysis

The data documentation officer performs all data analysis and reduction. All data sheets are submitted to him for compilation onto master raw data sheets as shown in Tables 15, 16, and 17. The ultimate responsibility for proper data collection, analysis and presentation belongs to the OHMSETT Project Engineer. He writes the final report and disseminates data to the EPA Project Officer.

TEST DATA

Tables 15, 16, and 17 contain information on the test fluid properties, ambient conditions, and wave characteristics at the time the skimmer was tested. Performance data includes recovery rate (total HM/water combined), percent test fluid (HM% in the recovered fluids) and percent water (water % in the recovered fluids). HM recovery rate was obtained by multiplying the recovery rate by the percent test fluid. The percent test fluid is also defined as recovery efficiency.

STATIONARY SKIMMER TEST RESULTS - DISCUSSION

The performance parameters for stationary skimmer systems were recovery rate, and recovery efficiency. There was no clear relationship between the physical properties of the test fluids. In addition, specific wave conditions as given in the test matrix table were simulated to note water surface effects on skimmer performance. The significance of test fluid properties, and surface conditions on performance were tested by utilizing the OHMSETT standardized performance test plan. Each device was subjected to identically controlled conditions to facilitate a fair evaluation of performance criteria.

The floating suction head skimmer performed slightly better with the more viscous DOP (67.5 cSt) than with less viscous HM under a calm surface condition. When waves were introduced, however, the DOP tended to become mixed into the water column. Under this condition, the performance of the floating suction head skimmer was optimized with Naphtha. It is interesting to note that except with DOP, the nominal 0.6 m harbor chop did not significantly affect recovery rate (see Figures 5 and 6).

The self-adjusting weir-type skimmer exhibited recovery efficiencies approaching 40% when tested with DOP and a calm surface condition. As with the floating suction head skimmer, efficiency was maximized with the higher density HM. When confronted with the wave condition, the total mixture recovery rate increased as more water was skimmed, but recovery efficiency dropped (see Figures 7 and 8 for details).

The third stationary skimmer design studied was the oleophilic rope type skimmer. Recovery efficiency approached 100% with DOP and a calm surface condition. Performance in waves was optimized near 80% recovery efficiency. Hydrodynamic forces were somewhat overcome by the adsorption force on the test fluid by the oleophilic rope. See Figures 9 and 10 for details.

In general, the stationary skimmers performed remarkedly well in the 0.6 m (2 ft) harbor chop wave condition. This was a breaking wave which effectively entrained the test material (Naphtha, Octanol, and DOP) nearly 0.3 m (1 ft) into the water column. However, since the test was designed for thick slick (2.0 cm) performance, more than 80% of the HM was floating on the water surface at any given time during the tests. Perhaps this accounts for the lack of a strong effect by either waves or type of HM on the stationary skimmer performance.

TABLE 15. TEST RESULTS SLICKBAR SKIMMER MARLOW PUMP

DATE	TIME	TEST NUMBER	TEST FLUIDS PROPERTIES						AMBIENT CONDITIONS									WAVE CHARACTERISTICS				PERFORMANCE CHARACTERISTICS		
			TYPE	TEMPERATURE °C	VISCOSITY m^2/sec. x 10^{-6}	SURFACE TENSION N/m x 10-3	INTERFACIAL N/m x 10-3	SPECIFIC GRAVITY	AIR TEMPERATURE °C	WIND SPEED m/sec	WIND DIRECTION							HEIGHT meters	LENGTH meters	PERIOD sec.		RECOVERY RATE m^3/sec. x 10^{-3}	% TEST FLUID	% WATER
10/3	1145	1	OCT	17.8	13.3	25.3	7.7	.8310	17.8	3.1	SW							0	0			4.34	17.6	82.4
10/3	1155	1R	OCT	17.8	13.3	25.3	7.7	.8310	17.8	3.1	SW							0	0			4.31	14.9	85.1
10/3	1215	1R^2	OCT	17.8	13.6	26.4	7.6	.8340	17.8	3.1	SW							0	0			4.34	17.3	82.7
10/6	0953	6	OCT	17.8	13.6	26.4	7.6	.8340	29.4	1.8	SW							0.6	HC			4.56	11.3	88.7
10/6	1120	7	NAP	16.7	6.5	23.2	11.1	.7730	29.4	2.2	SW							0	0			4.77	27.3	72.7
10/6	1509	12	NAP	16.7	6.5	23.2	11.1	.7730	33.3	2.2	SW							0.6	HC			4.83	15.9	84.1
10/7	1020	13	DOP	15.6	79.2	29.2	15.8	.9770	23.9	1.3	S							0	0			3.71	40.1	59.9
10/7	1352	18	DOP	15.6	79.2	29.2	15.8	.9770	28.3	0.9	SW							0.6	HC			4.23	22.4	77.6
10/7	1435	19	DOP	15.6	79.2	29.2	15.8	.9770	31.1	0.9	SE							0	0			4.36	31.7	68.3
10/8	1030	20	DOP	15.6	79.2	29.2	15.8	.9770	24.4	0.4	SW							0	0			6.00	19.1	80.9
10/8	1040	21	DOP	15.6	79.2	29.2	15.8	.9770	24.4	0.4	S							0	0			6.47	19.3	80.7
10/8	1045	22	DOP	15.6	79.2	29.2	15.8	.9770	24.4	0.4	S							0	0			6.44	25.5	74.5

(Continued)

TABLE 15. (Continued)

			TEST FLUIDS PROPERTIES						AMBIENT CONDITIONS															
DATE	TIME	TEST NUMBER	TYPE	TEMPERATURE °C	VISCOSITY m^2/sec. x 10^{-6}	SURFACE TENSION N/m x 10-3	INTERFACIAL N/m x 10-3	SPECIFIC GRAVITY	AIR TEMPERATURE °C	WIND SPEED m/sec.	WIND DIRECTION							HEIGHT meters	LENGTH meters	PERIOD meters		RECOVERY RATE m^3/sec x 10^{-3}	% TEST FLUID	% WATER
10/8	1050	23	DOP	15.6	79.2	29.2	15.8	.9770	25.0	1.8	SW							0	0			6.50	27.5	72.5

TABLE 16. TEST RESULTS I.M.E. SKIMMER SANDPIPER PUMP

			TEST FLUIDS PROPERTIES						AMBIENT CONDITIONS									WAVE CHARACTERISTICS				PERFORMANCE CHARACTERISTICS		
DATE	TIME	TEST NUMBER	TYPE	TEMPERATURE °C	VISCOSITY m^2/sec. x 10^{-6}	SURFACE TENSION N/m x 10-3	INTERFACIAL N/m x 10-3	SPECIFIC GRAVITY	AIR TEMPERATURE °C	WIND SPEED m/sec.	WIND DIRECTION							HEIGHT meters	LENGTH meters	PERIOD meters		RECOVERY RATE m^3/sec x 10^{-3}	% TEST FLUID	% WATER
10/3	1336	2	OCT	17.8	13.3	25.3	7.7	.8310	18.9	2.2	SW							0	0			4.03	28.9	71.1
10/6	0930	5	OCT	17.8	13.6	26.4	7.6	.8340	29.4	2.2	W							0.6	HC			5.23	22.5	77.5
10/6	1140	8	NAP	16.7	6.5	23.2	11.1	.7730	30.6	2.7	SW							0	0			3.95	31.2	68.8
10/6	1453	11	NAP	16.7	6.5	23.2	11.1	.7730	33.3	2.2	SW							0.6	HC			5.70	25.1	74.9
10/7	1040	14	DOP	15.6	79.2	29.2	15.8	.9770	24.4	2.7	SW							0	0			4.96	39.4	60.6
10/7	1330	17	DOP	15.6	79.2	29.2	15.8	.9770	28.9	2.7	SW							0.6	HC			5.77	24.0	76.0

TABLE 17. TEST RESULTS OIL MOP SKIMMER OIL MOP PUMP

			TEST FLUIDS PROPERTIES						AMBIENT CONDITIONS									WAVE CHARACTERISTICS				PERFORMANCE CHARACTERISTICS		
DATE	TIME	TEST NUMBER	TYPE	TEMPERATURE °C	VISCOSITY $m^2/sec. \times 10^{-6}$	SURFACE TENSION $N/m \times 10^{-3}$	INTERFACIAL $N/m \times 10^{-3}$	SPECIFIC GRAVITY	AIR TEMPERATURE °C	WIND SPEED m/sec.	WIND DIRECTION							HEIGHT meters	LENGTH meters	PERIOD sec.		RECOVERY RATE $m^3/sec. \times 10^{-3}$	% TEST FLUID	% WATER
10/3	1440	3	OCT	17.8	13.3	25.3	7.7	.8310	23.3	1.8	SW							0	0			0.85	78.9	21.1
10/3	1547	4	OCT	17.8	13.6	26.4	7.6	.8340	25.6	3.6	W							0.6	HC			1.14	70.0	30.0
10/6	1245	9	NAP	16.7	6.5	23.2	11.1	.7730	32.2	4.5	W							0	0			0.73	88.6	11.4
10/6	1345	10	NAP	16.7	6.5	23.2	11.1	.7730	32.8	5.4	SW							0.6	HC			0.96	68.3	31.7
10/7	1120	15	DOP	15.6	79.2	29.2	15.8	.9770	24.4	1.3	S							0	0			2.78	98.3	1.7
10/7	1145	16	DOP	15.6	79.2	29.2	15.8	.9770	25.0	2.7	S							0.6	HC			2.02	72.6	27.4

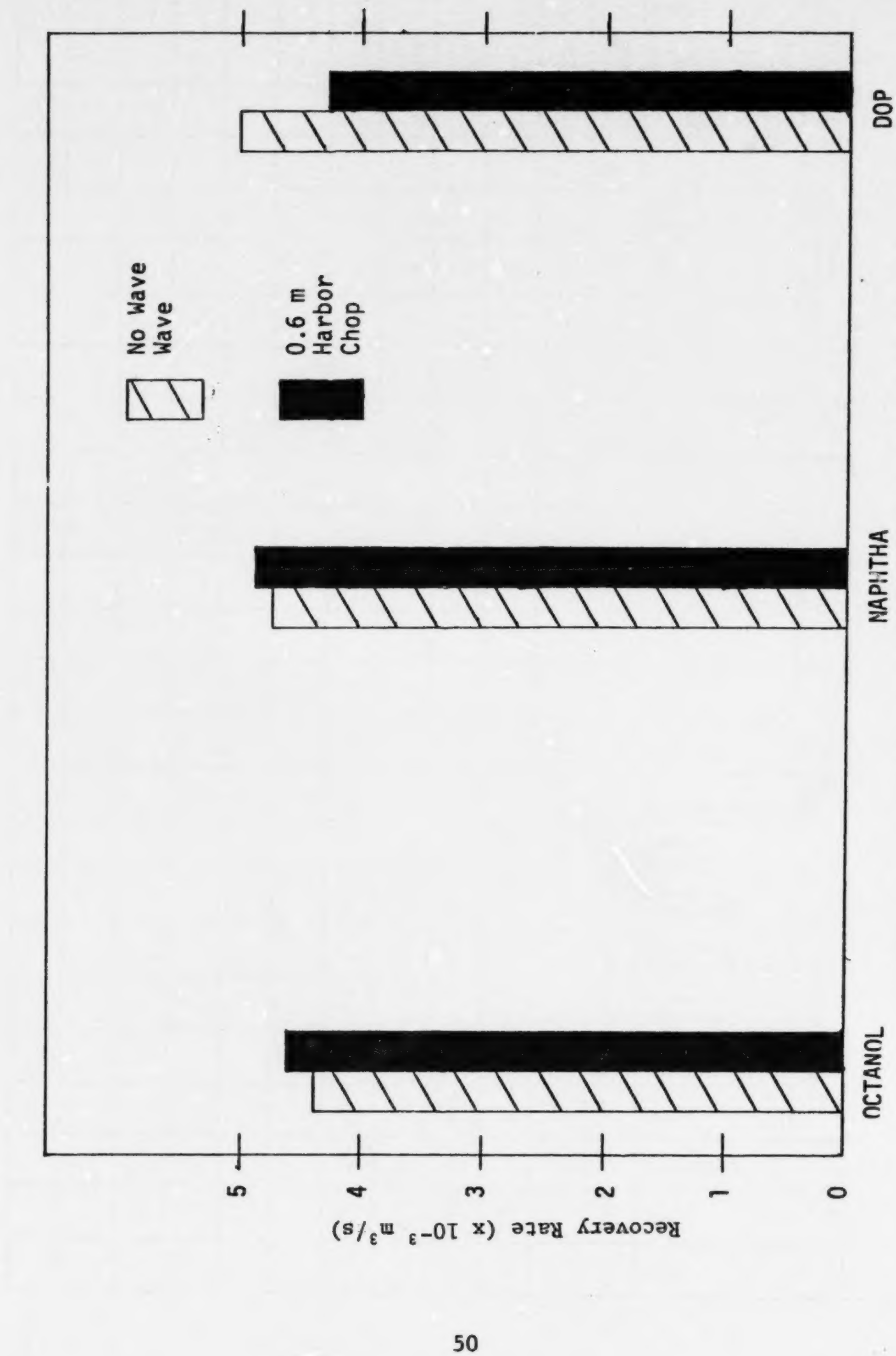

Figure 5. Recovery rate of the Slickbar Rigid Mantaray.

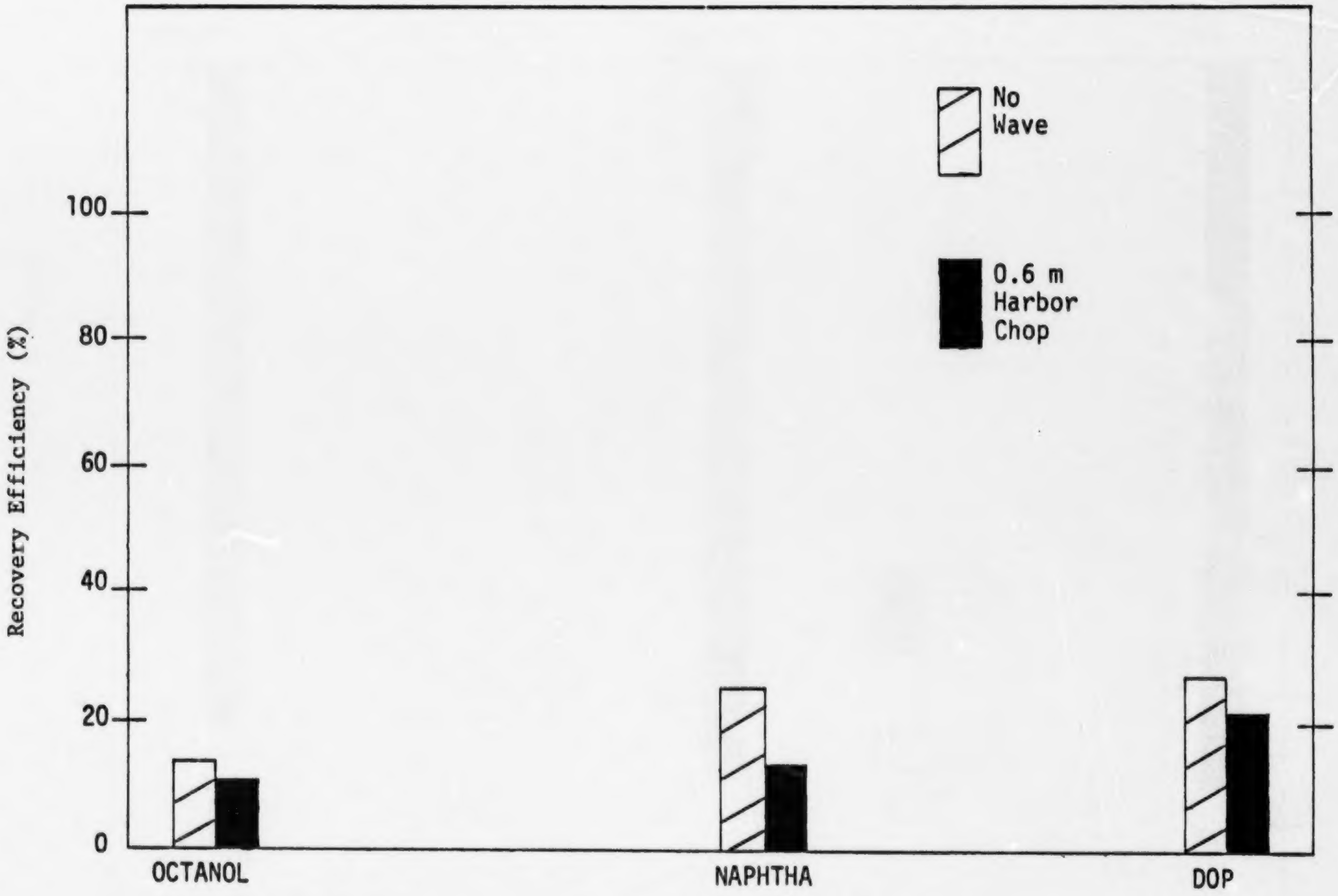

Figure 6. Recovery efficiency of the Slickbar Rigid Mantaray.

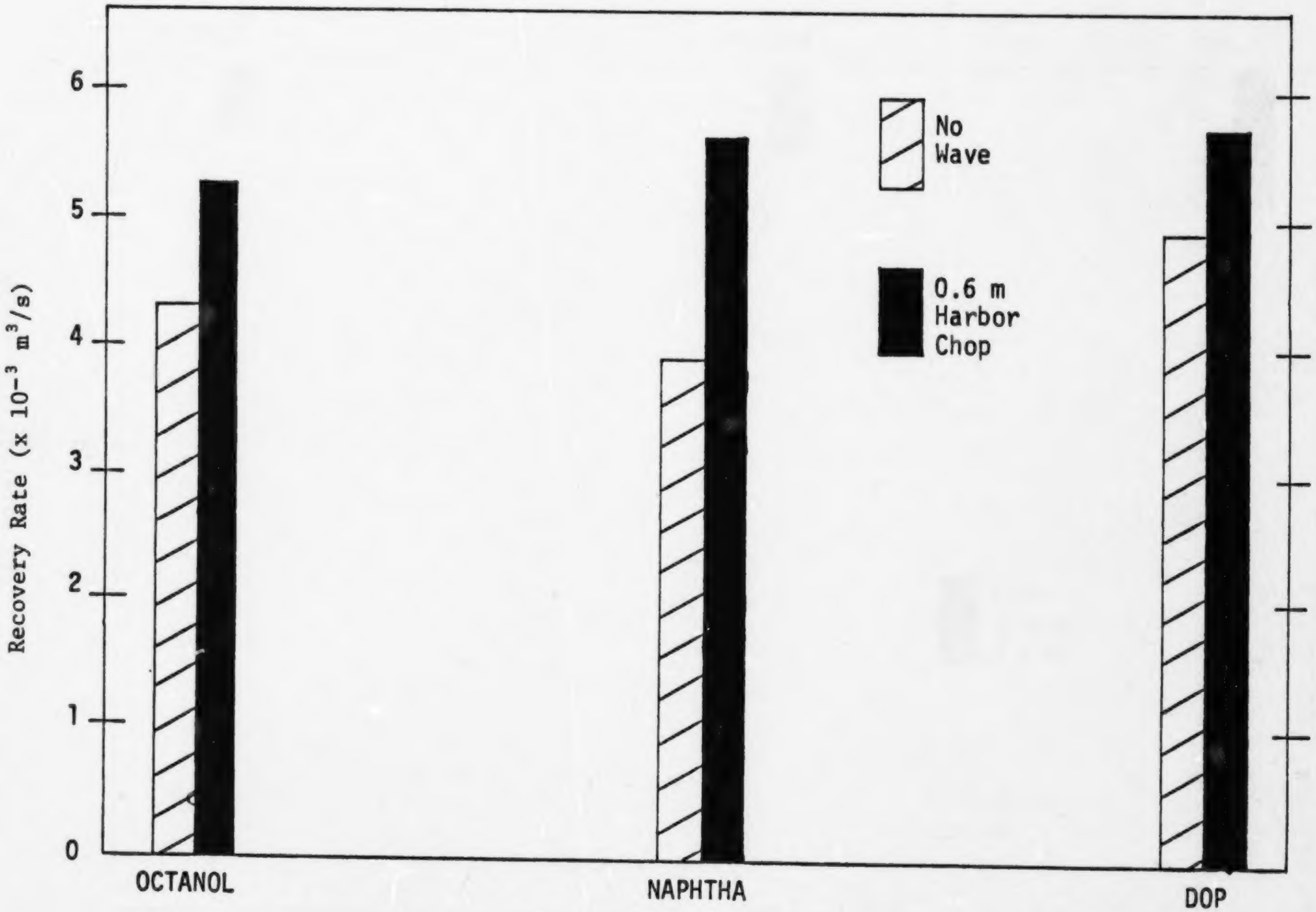

Figure 7. Recovery rate of the I.M.E. Swiss OELA.

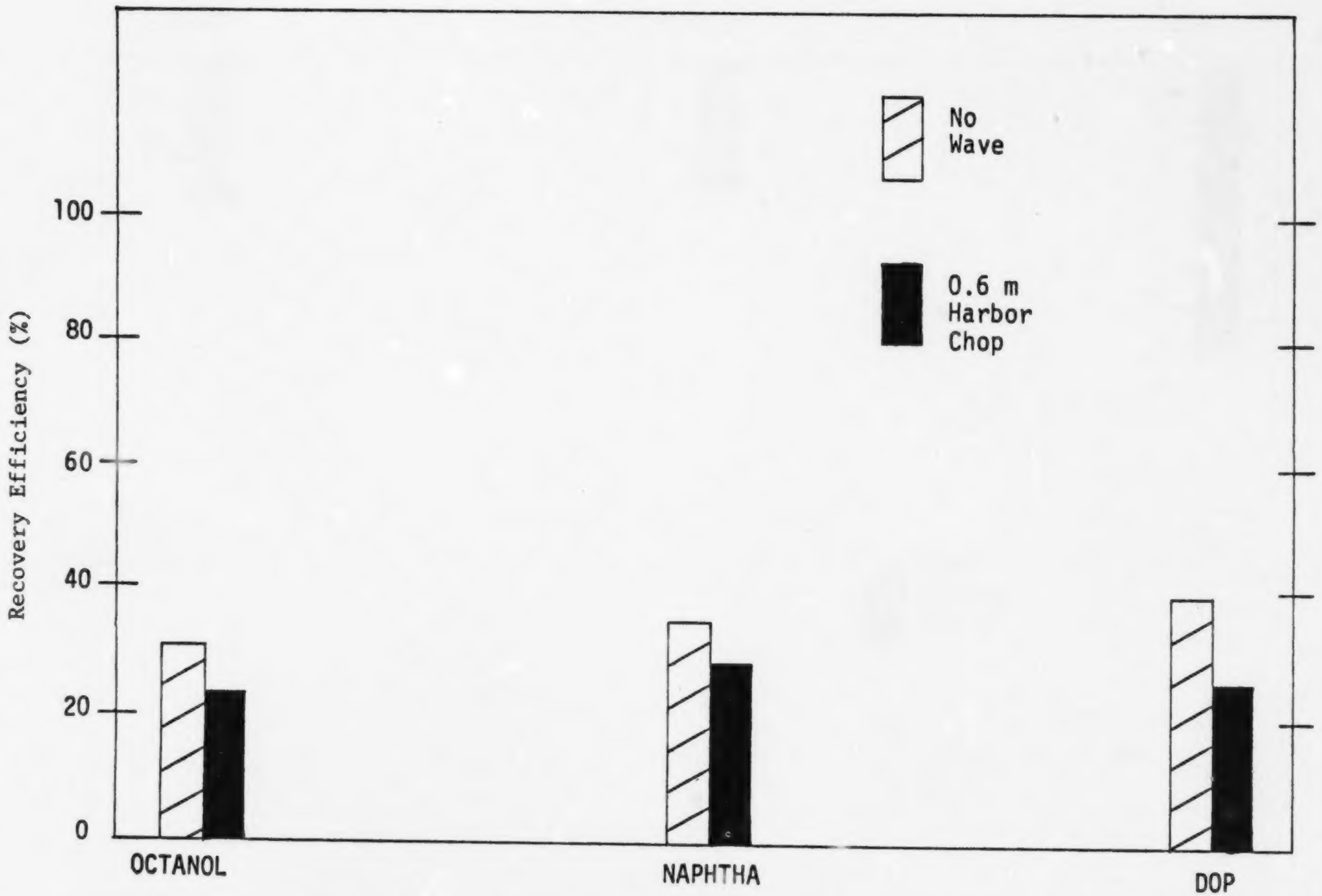

Figure 8. Recovery efficiency of the I.M.E. Swiss OELA.

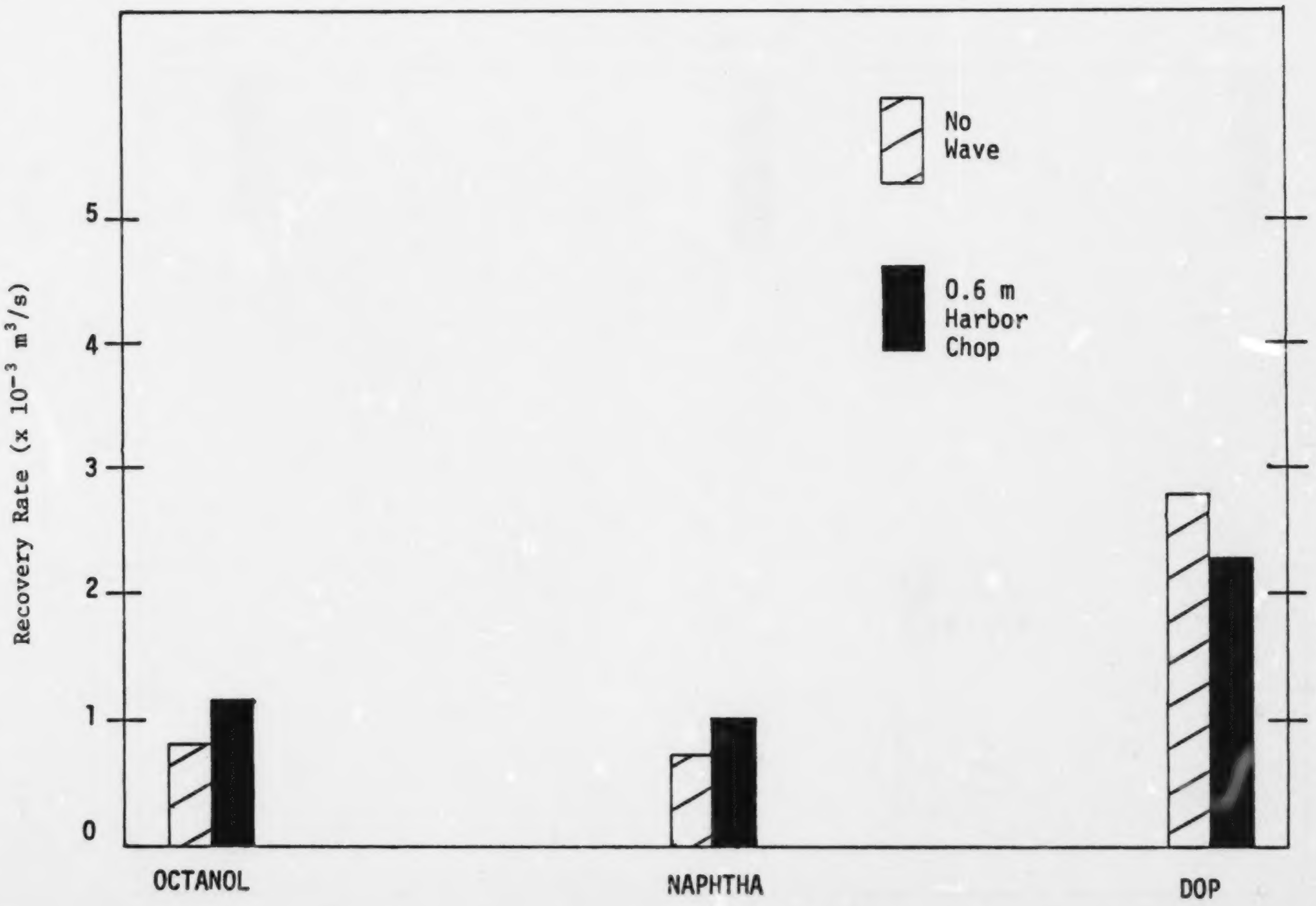

Figure 19. Recovery rate of the Oil Mop.

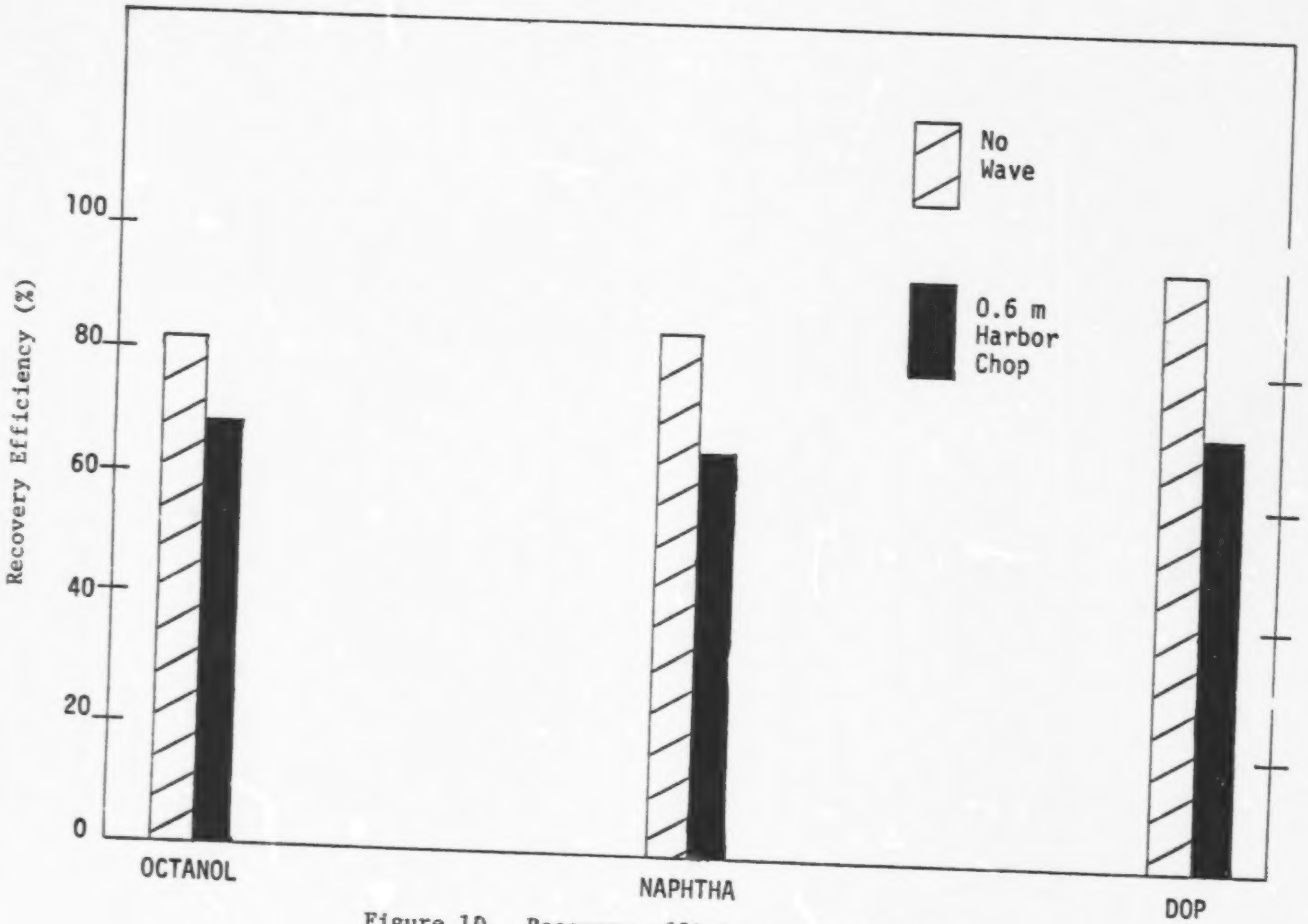

Figure 10. Recovery efficiency of the Oil Mop.

SECTION 8

ADVANCING SKIMMER TESTS

ADVANCING SKIMMER TEST PROCEDURE

Preliminary deployment and rigging of these test devices was done according to manufacturer's recommendations. Of substantial importance was establishing manpower distribution (Figure 11) and the test procedure. Parameters such as belt speed and on-board pump rate were established by customer representatives and manufacturer's recommendations.

Once all systems were in operation, shakedown runs were performed to note the stability of the device under tow and to ensure the proper sequence of events during actual test runs.

Performance testing began subsequently when the desired surface condition, tow speed, and oil distribution were initiated. On signal from the test director, steady state data collection began.

The tow tests were conducted by distribution of the HM in a 2 mm (0.08 in) thick, 1.52 m (5 ft) wide spill. The device was then towed through the slick at various speeds from 0.0254 m/s to 1.01 m/s (0.5-2.0 kt); the steady state test time was established at 60 s. At the end of the test run, the total recovered fluid, recovery time and temperature of the test fluid were measured. Total recovery rate was determined by measuring the total volume of recovered HM/water mixture and the duration of the test run. The volume of water in the recovered mixture was read through translucent tanks, after allowing the water to settle out of the HM gravitationally for a minimum of 1/2 h. Recovery efficiency was documented as the percent of HM recovered. HM recovery rate was then calculated by simply multiplying the total recovery rate by HM recovery efficiency. The test matrices are given in Tables 5 and 6.

A step-by-step test procedure for advancing skimmers is given below in the following format: Manpower Allocations, Pre-test Checklist, Test Sequence, Data Sheets and Data Analysis.

Manpower Allocations

The following allocations of duties were made:

1. Test director - responsible for running the tests according to the prescribed test matrix and test procedure. Manages the test

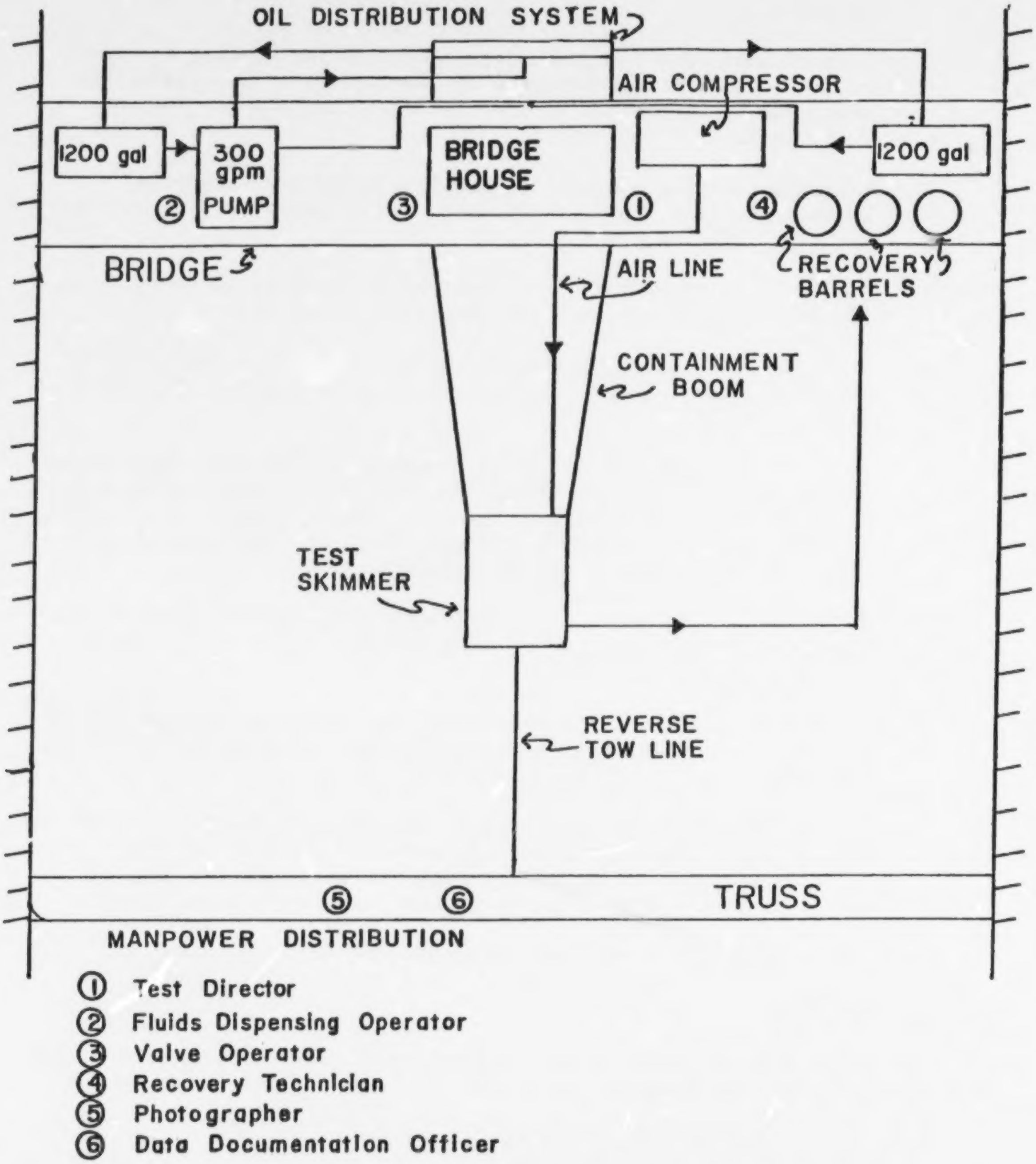

Figure 11. Advancing skimmer test details.

personnel.

2. Control room operator - operates the traveling bridge, wave generator and bubbler barrier from the control tower located at the north end of the tank. He also collects the data for ambient conditions.

3. Fluids dispensing operator - usually a temporary technician who adjusts the flow control valves for the proper flow rate and records the flow rate.

4. Data documentation officer - observes and records recovery volumes and performs the analysis and reduction of all data.

5. Photographer - photographically documents the test runs with 35 mm color slides, 16 mm color motion pictures, and/or underwater video tape.

6. Chemical analysis officer - takes samples of the test fluid before its distribution and after its recovery for analysis of water content, viscosity, specific gravity, and interfacial tension for the test run. In general, analysis of fluids for chemical and physical properties is his responsibility.

7. Valve operator - usually a temporary technician who operates the pneumatic valve controls for recirculation and distribution of the test fluid.

8. Fluids clean up team leader - heads the operation of cleaning the residual test fluid from the water surface in preparation for the next test run.

9. Fluids refurbishment team leader - heads the operation of removing water (both free and emulsified) and contaminants from the test fluid prior to its reuse. Also, responsible for operating the d.e. filter unit to maintain tank water purity and clarity.

10. Other temporary aides were positioned as required.

Pre-test Checklist

To ensure that all test systems and equipment were maintained and ready for the test, the following checklist was used prior to the first test run:

1. D.E. Filter system operating
2. Chlorine generator operating
3. Air-bubble barrier system operating
4. Bridge drive system operating
5. Wave generator system operational
6. Test device operational
7. Test instrumentation operational

8. Test fluid ready
9. Test fluid distribution system operational
10. Test support equipment operational
11. Photographic systems ready
12. Test personnel prepared and ready
13. Complete all pre-run data sheets and checklists

Test Sequence (with test fluid)

The following test sequence was used for the advancing skimmer tests:

1. Position the traveling bridge and test device for testing (see Figure 11).

2. Position all test personnel for testing (see Figure 11).

3. Inform all test personnel of test conditions taken from the test matrix.

4. Calibrate the flow rate using the recirculation mode, and continue to recirculate while observing test fluid temperature and pressure drop. Just prior to test run, take samples of recirculating test fluid and record test fluid temperature.

5. Establish required test device parameters (i.e. belt speed, air supply to on-board pump, etc.).

6. Position recovery hose to discharge back onto tank surface.

7. Give three (3) blasts on the air horn to clear the tank decks, alert all test personnel of test run, and start the wave generator, if required.

8. Using either intercom system or walkie-talkies, begin countdown from five (5), with the control room operator to begin bridge motion at zero (0) and one (1) blast on the air horn.

9. One (1) blast on the air horn initiates the following: start bridge, start test fluid distribution, and start stopwatches.

10. Control room operator informs test director of established bridge tow speed.

11. Test director observes position of truss near the "designated" tank position to signify approach of steady state.

12. At designated point, all personnel are signaled to start stopwatches for 1 min steady state run.

13. On signal from test director, recovery hose is directed to collection barrels for a period of 1 min.

14. Test fluid distribution ceases after steady state collection, and distribution time is recorded.

15. Test director begins countdown from five (5) to stop the bridge and wave generator.

16. Lower the bridge "skimming plate" to prevent test fluid from passing under the bridge and to skim all residual test fluid back to the north end surface containment area.

17. Measure the total recovered test fluid, recovery time and temperature of the test fluid.

18. Measure the collected test fluid after allowing the water to settle out for at least 1/2 h.

19. Take samples of the test fluid layer for analysis.

20. Reverse the bridge to prepare for the next test run.

Data Sheets

The following data sheets were used for the advancing skimmer tests:

1. Chemistry Laboratory Analysis
2. Flow Rate/Volume Data Sheet
3. Ambient Conditions Data Sheet
4. Advancing Skimmer Test Data Sheet
5. Test Equipment Characteristics and Rigging Specifications

Data Analysis

The data documentation officer performs all data analysis and reduction. All data sheets are submitted to him for compilation onto master raw data sheets as shown in Tables 18 and 19. The ultimate responsibility for proper data collection, analysis and presentation belongs to the OHMSETT Project Engineer. He writes the final report and disseminates data to the EPA Project Officer.

TEST DATA

Tables 18 and 19 contain information on the test fluid properties, ambient conditions and wave characteristics at the time the skimmer was tested. The recovery rate column on the test results table lists the rate at which the equipment recovers the HM/water mixture under test conditions. The throughput efficiency is the percentage of HM recovered to the amount encountered by the skimmer. The recovery efficiency is the percentage of HM recovered in the total mix. Results must be viewed in light of the fact that a steady state of testing was maintainable for only 60 s or less. In a real world environment, the skimmers would probably be towed at a much greater distance than is possible at the OHMSETT facility,

TABLE 18. TEST RESULTS DIP-1002

DATE	TIME	TEST NUMBER	TEST FLUIDS PROPERTIES						AMBIENT CONDITIONS			SLICK CHARACTERISTICS				TOW SPEED m/sec.	STEADY STATE TEST TIME sec.	TEST EQUIPMENT SETTINGS				PERFORMANCE CHARACTERISTICS		
			TYPE	TEMPERATURE °C	VISCOSITY m^2/sec. x 10^{-6}	SURFACE TENSION N/m x 10^{-3}	INTERFACIAL N/m x 10^{-3}	SPECIFIC GRAVITY	AIR TEMPERATURE °C	WIND SPEED m/sec.	WIND DIRECTION	DISTRIBUTION RATE m^3/sec x10^{-3}	SLICK THICKNESS mm	HEADWAVE START meters	HEADWAVE FINISH meters			BELT SPEED m/sec	BELT SPEED/TOW SPEED			RECOVERY RATE m^3/sec. x 10^{-3}	THRUPUT EFF. %	RECOVERY EFF. %
9/24	1240	ST-3	NAP	17.8	6.8	23.5	18.2	.771	17.2	4.5	NE	3.6	1.9			1.27	30	1.2	0.9			1.21	33.3	37.6
9/24	1305	6A	NAP	17.8	6.8	23.5	18.2	.771	17.8	4.5	NE	2.0	2.0			0.63	60	1.2	1.9			0.22	11.3	6.9
9/24	1330	6B	NAP	17.8	6.8	23.5	18.2	.771	17.8	4.5	NE	1.9	2.0			0.63	60	1.2	1.9			0.24	12.3	7.4
9/25	0900	1	DOP	15.6	92.0	24.9	16.4	.987	15.6	6.7	NE	2.4	2.1			0.76	60	1.2	1.6			0.20	8.5	6.4
9/25	0930	2	DOP	15.6	92.0	24.9	16.4	.987	16.4	6.7	NE	2.7	2.0			0.89	60	1.2	1.4			0.10	3.7	3.2
9/25	1030	3	DOP	15.6	92.0	24.9	16.4	.987	15.6	6.7	NE	2.0	2.1			0.63	60	1.2	1.9			0.10	5.1	3.1
9/25	1115	4	DOP	15.6	92.0	24.9	16.4	.987	15.6	6.7	NE	1.6	2.0			0.51	60	1.2	2.4			0.40	25.6	12.5
9/25	1130	5	DOP	15.6	92.0	24.9	16.4	.987	15.6	8.9	N	1.2	2.0			0.38	60	1.2	3.2			0.62	52.7	19.1
9/25	1155	6	DOP	15.6	92.0	24.9	16.4	.987	16.1	11.2	N	0.8	2.1			0.25	60	1.2	4.8			0.68	85.0	20.1
9/25	1305	7	DOP	15.6	92.0	24.9	16.4	.987	16.1	11.2	E	0.8	2.1			0.25	60	0	0			0.10	12.5	3.1

(Continued)

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TABLE 18. (Continued)

DATE	TIME	TEST NUMBER	TEST FLUIDS PROPERTIES						AMBIENT CONDITIONS			SLICK CHARACTERISTICS				TOW SPEED m/sec.	STEADY STATE TEST TIME sec.	TEST EQUIPMENT SETTINGS				PERFORMANCE CHARACTERISTICS		
			TYPE	TEMPERATURE °C	VISCOSITY m^2/sec. x 10^{-6}	SURFACE TENSION N/m x 10^{-3}	INTERFACIAL N/m x 10^{-3}	SPECIFIC GRAVITY	AIR TEMPERATURE °C	WIND SPEED m/sec.	WIND DIRECTION	DISTRIBUTION RATE m^3/sec x10^{-3}	SLICK THICKNESS mm	HEADWAVE START meters	HEADWAVE FINISH meters			BELT SPEED m/sec	BELT SPEED/ TOW SPEED			RECOVERY RATE m^3/sec. x 10^{-3}	THRUPUT EFF. %	RECOVERY EFF. %
9/23	1015	3A	OCT	16.7	12.4	26.2	7.6	.836	15.6	4.5	SE	2.0	2.1			0.63	60	1.1	1.7			0.61	30.3	20.5
9/23	1045	3B	OCT	16.7	12.4	26.2	7.6	.836	15.6	4.5	SE	2.0	2.1			0.63	60	1.1	1.7			0.71	35.6	23.2
9/23	1120	4	OCT	16.7	12.4	26.2	7.6	.836	15.6	3.6	E	2.3	2.1			0.76	60	1.1	1.4			0.81	34.8	26.2
9/23	1140	5	OCT	16.7	12.4	26.2	7.6	.836	15.6	3.6	E	1.6	2.0			0.51	60	1.1	2.2			0.74	47.6	24.8
9/23	1250	ST-1	OCT	16.7	12.4	26.2	7.6	.836	16.1	3.6	E	2.7	2.0			0.89	60	1.1	1.2			1.23	45.0	39.4
9/23	1315	ST-2	OCT	16.7	12.4	26.2	7.6	.836	16.1	3.6	E	3.1	2.0			1.02	60	1.1	1.1			0.76	24.8	24.3
9/23	1410	3C	OCT	16.7	12.4	26.2	7.6	.836	16.1	3.6	E	2.0	2.1			0.63	60	1.1	1.7			0.83	40.8	25.6
9/24	0905	6	NAP	15.6	6.8	23.5	18.2	.771	16.1	4.5	E	1.9	2.0			0.63	60	1.2	1.9			0.08	4.2	2.7
9/24	1000	7	NAP	17.2	6.8	23.5	18.2	.771	16.1	4.5	E	2.3	2.1			0.76	60	1.2	1.6			0.62	26.9	19.6
9/24	1015	8	NAP	17.8	6.8	23.5	18.2	.771	16.1	4.5	NE	2.7	2.0			0.89	60	1.2	1.4			1.01	37.6	31.5
9/24	1055	ST-1	NAP	17.2	6.8	23.5	18.2	.771	16.1	4.5	NE	3.1	2.0			1.02	60	1.2	1.2			1.33	43.2	41.5
9/24	1115	ST-2	NAP	17.2	6.8	23.5	18.2	.771	16.7	4.5	NE	3.5	2.0			1.14	30	1.2	1.1			1.38	39.8	42.7

TABLE 19. TEST RESULTS ORS-125.

			TEST FLUIDS PROPERTIES						AMBIENT CONDITIONS			SLICK CHARACTERISTICS						TEST EQUIPMENT SETTINGS				PERFORMANCE CHARACTERISTICS		
DATE	TIME	TEST NUMBER	TYPE	TEMPERATURE °C	VISCOSITY m^2/sec. x 10^{-6}	SURFACE TENSION N/m x 10^{-3}	INTERFACIAL N/m x 10^{-3}	SPECIFIC GRAVITY	AIR TEMPERATURE °C	WIND SPEED m/sec.	WIND DIRECTION	DISTRIBUTION RATE m^3/sec x10^{-3}	SLICK THICKNESS mm	HEADWAVE START meters	HEADWAVE FINISH meters	TOW SPEED m/sec.	STEADY STATE TEST TIME sec.	AIR SUPPLY TO PUMP x10^3N/m^2				RECOVERY RATE m^3/sec. x 10^{-3}	THRUPUT EFF. %	RECOVERY EFF. %
9/30	1045	6	NAP	18.3	6.69	23.5	27.1	.744	17.8	1.3	W	3.7	4.8	4.0	4.3	0.51	60	296				0	0	0
9/30	1125	7	NAP	18.3	6.69	23.5	27.1	.774	17.8	2.7	NW	6.1	3.9	1.2	1.2	1.02	60	296				0	0	0
9/30	1245	8	NAP	21.1	6.69	23.5	27.1	.774	22.2	1.8	S	5.2	4.5	2.7	3.0	0.76	60	290				0	0	0
9/30	1310	ST-1	NAP	21.1	6.69	23.5	27.1	.774	22.2	1.3	NE	7.2	3.1	1.5	1.8	1.52	20	296				0	0	0
9/30	1410	1	DOP	21.1	93.70	29.7	18.2	.986	22.2	1.3	W	3.2	4.1	0.6	0.6	0.51	60	296				0.30	9.6	6.0
9/30	1430	2	DOP	21.1	93.70	29.7	18.2	.986	22.2	3.1	NE	5.0	4.4	0.3	0.6	0.76	60	296				0.22	4.4	4.3
9/30	1530	3	DOP	21.1	93.70	29.7	18.2	.986	22.2	3.1	NE	1.8	4.6	1.5	1.2	0.25	60	296				1.09	61.4	21.6
10/1	1030	P3	DOP	15.6	93.70	29.7	18.2	.986	18.9	0.9	NW	1.6	4.1	0.6	1.2	0.25	60	276				1.41	89.6	27.8
10/1	1045	P4	DOP	15.6	93.70	29.7	18.2	.986	18.9	2.2	N	1.6	4.1	1.2	0.9	0.25	60	276				1.45	92.0	28.6
10/1	1145	P5	DOP	18.9	93.70	29.7	18.2	.986	22.2	1.8	N	1.6	4.1	1.2	1.2	0.25	60	276				1.10	70.0	22.3
10/1	1300	P2	DOP	23.3	93.70	29.7	18.2	.986	22.2	3.1	E	1.6	4.2	0.9	0.6	0.25	60	276				1.41	86.2	27.8
10/1	1320	P1	DOP	23.3	93.70	29.7	18.2	.986	22.2	4.5	E	1.6	4.1	0.6	0.6	0.25	60	276				1.27	80.4	25.5

(Continued)

TABLE 19. (Continued)

DATE	TIME	TEST NUMBER	TEST FLUIDS PROPERTIES						AMBIENT CONDITIONS			SLICK CHARACTERISTICS				TOW SPEED m/sec.	STEADY STATE TEST TIME sec.	TEST EQUIPMENT SETTINGS				PERFORMANCE CHARACTERISTICS		
			TYPE	TEMPERATURE °C	VISCOSITY m^2/sec. x 10^{-6}	SURFACE TENSION N/m x 10^{-3}	INTERFACIAL N/m x 10^{-3}	SPECIFIC GRAVITY	AIR TEMPERATURE °C	WIND SPEED m/sec.	WIND DIRECTION	DISTRIBUTION RATE m^3/sec x10^{-3}	SLICK THICKNESS mm	HEADWAVE START meters	HEADWAVE FINISH meters			AIR SUPPLY TO PUMP X10^3N/m^2				RECOVERY RATE m^3/sec. x 10^{-3}	THRUPUT EFF. %	RECOVERY EFF. %
10/1	0900	4	DOP	15.6	93.70	29.7	18.2	.986	16.7	0.9	W	2.5	4.4	0	0.3	0.38	60	276				0.37	14.5	7.2
10/1	0935	5	DOP	15.6	93.70	29.7	18.2	.986	16.7	0.9	W	0.9	4.6	2.4	3.0	0.13	60	276				0.40	45.7	8.0
10/2	915	9	OCT	16.7	13.30	25.3	7.7	.931	17.2	3.1	SE	3.8	4.0	5.0	7.0	0.64	60	221				0.65	16.9	14.3
10/2	1120	10R	OCT	16.7	13.30	25.3	7.7	.831	17.8	4.5	S-SW	5.9	4.3	0.9	0.9	0.89	60	345				1.37	23.3	25.1
10/2	1320	10R2	OCT	15.6	13.60	25.3	7.7	.831	16.7	5.8	SW	5.8	4.3	0.9	0.9	0.89	25	345				0.71	12.4	13.2
10/2	1355	11	OCT	15.6	13.60	25.3	7.7	.831	16.7	6.3	S-SW	6.2	4.0	0.6	0.9	1.02	60	414				1.19	19.2	20.0
10/2	1430	12	OCT	15.6	13.60	25.3	7.7	.831	16.7	6.7	S-SW	4.7	4.1	0.6	0.9	0.76	60	414				1.49	31.5	30.1

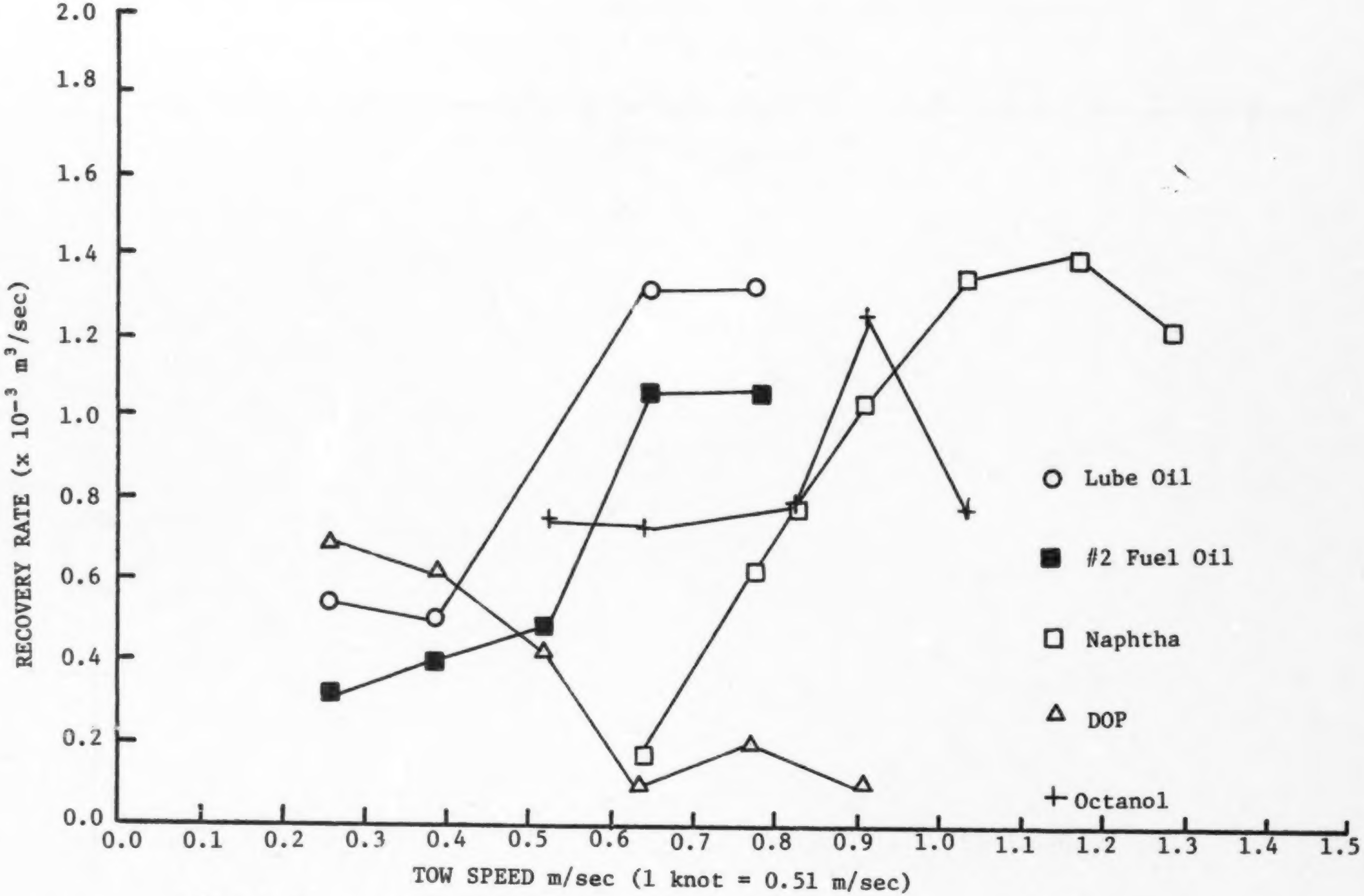

Figure 12. Hazardous material recovery rate vs. tow speed DIP-1002.

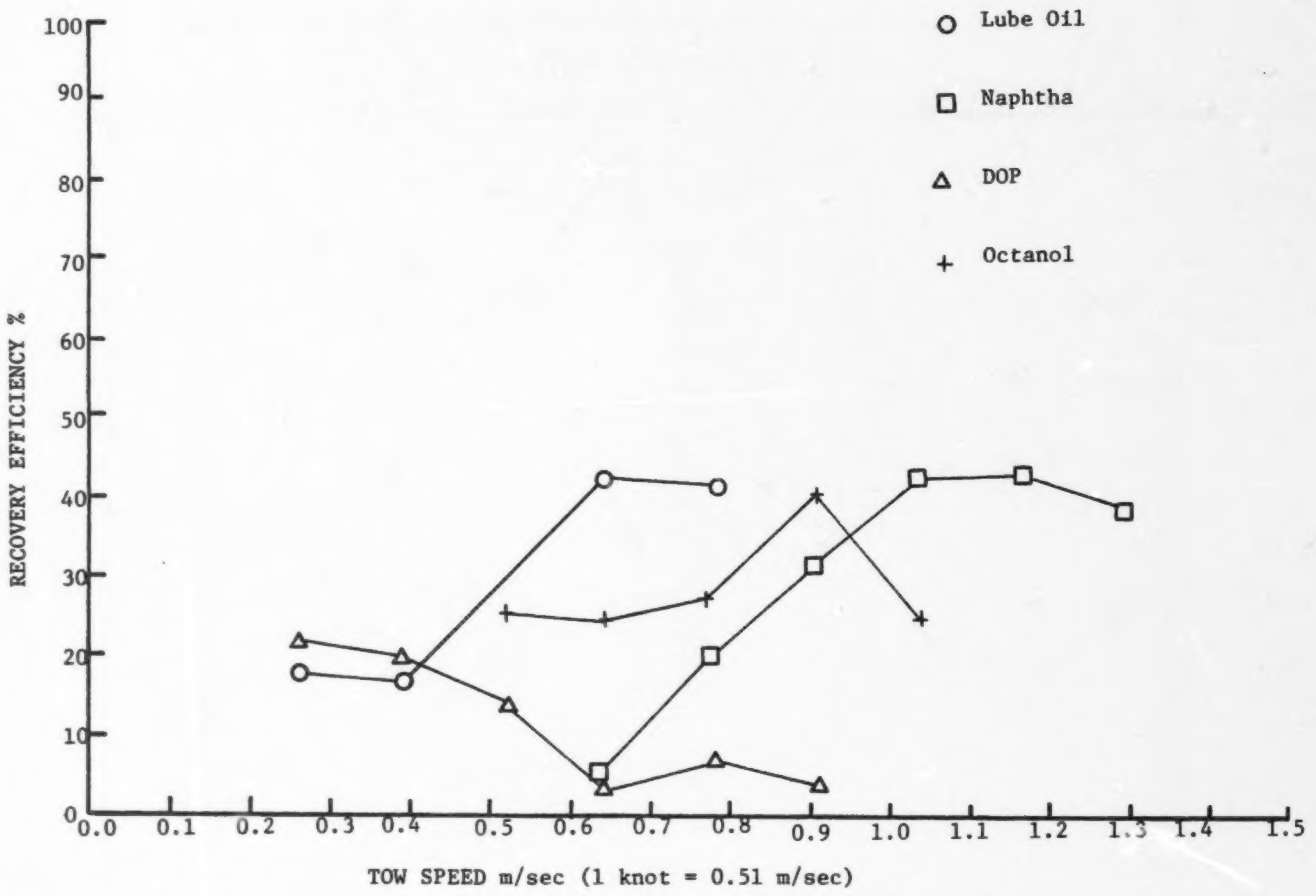

Figure 13. Hazardous material recovery efficiency vs. tow speed DIP-1002.

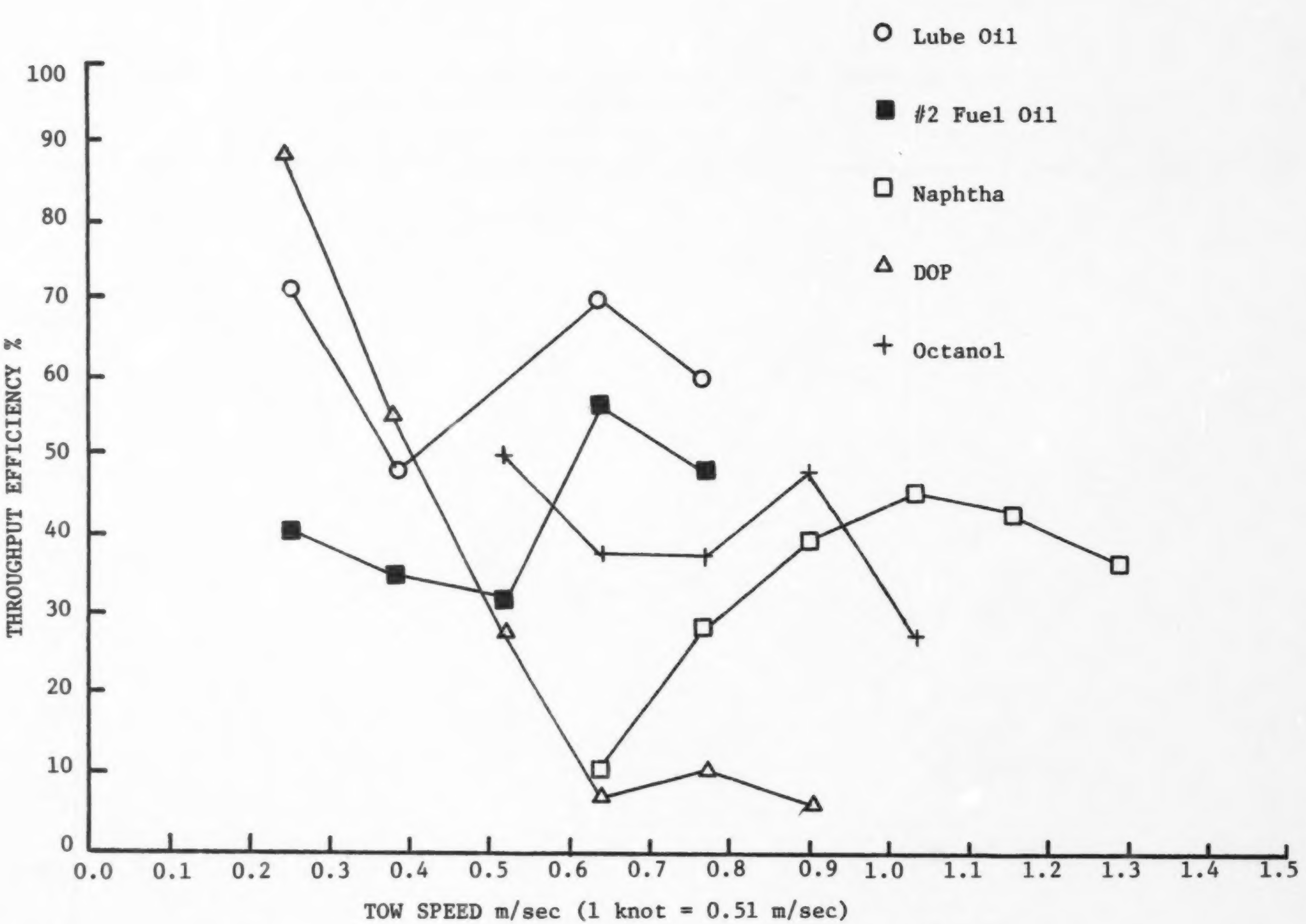

Figure 14. Throughput efficiency vs. tow speed DIP-1002.

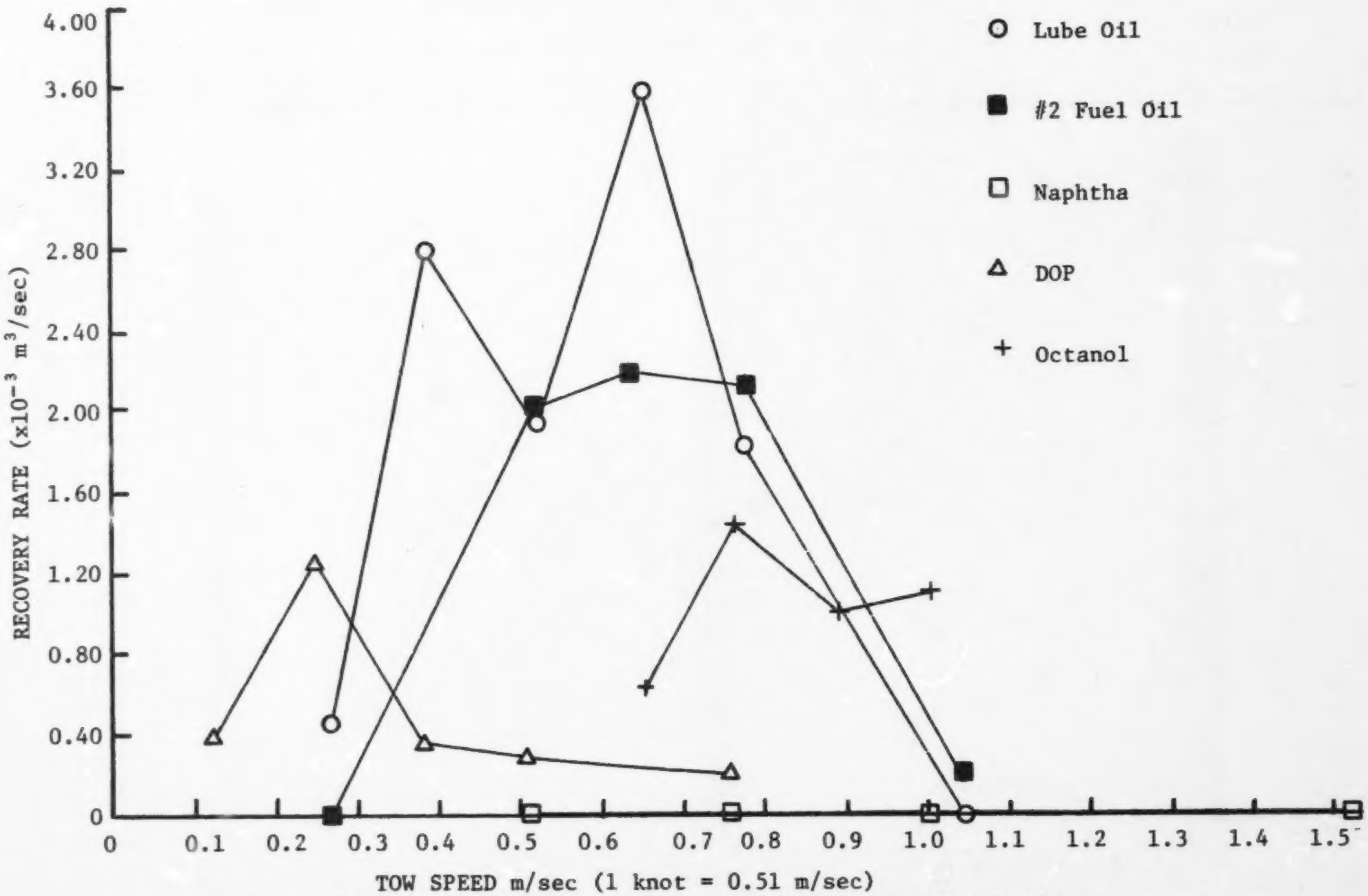

Figure 15. Hazardous material recovery rate vs. tow speed ORS-125.

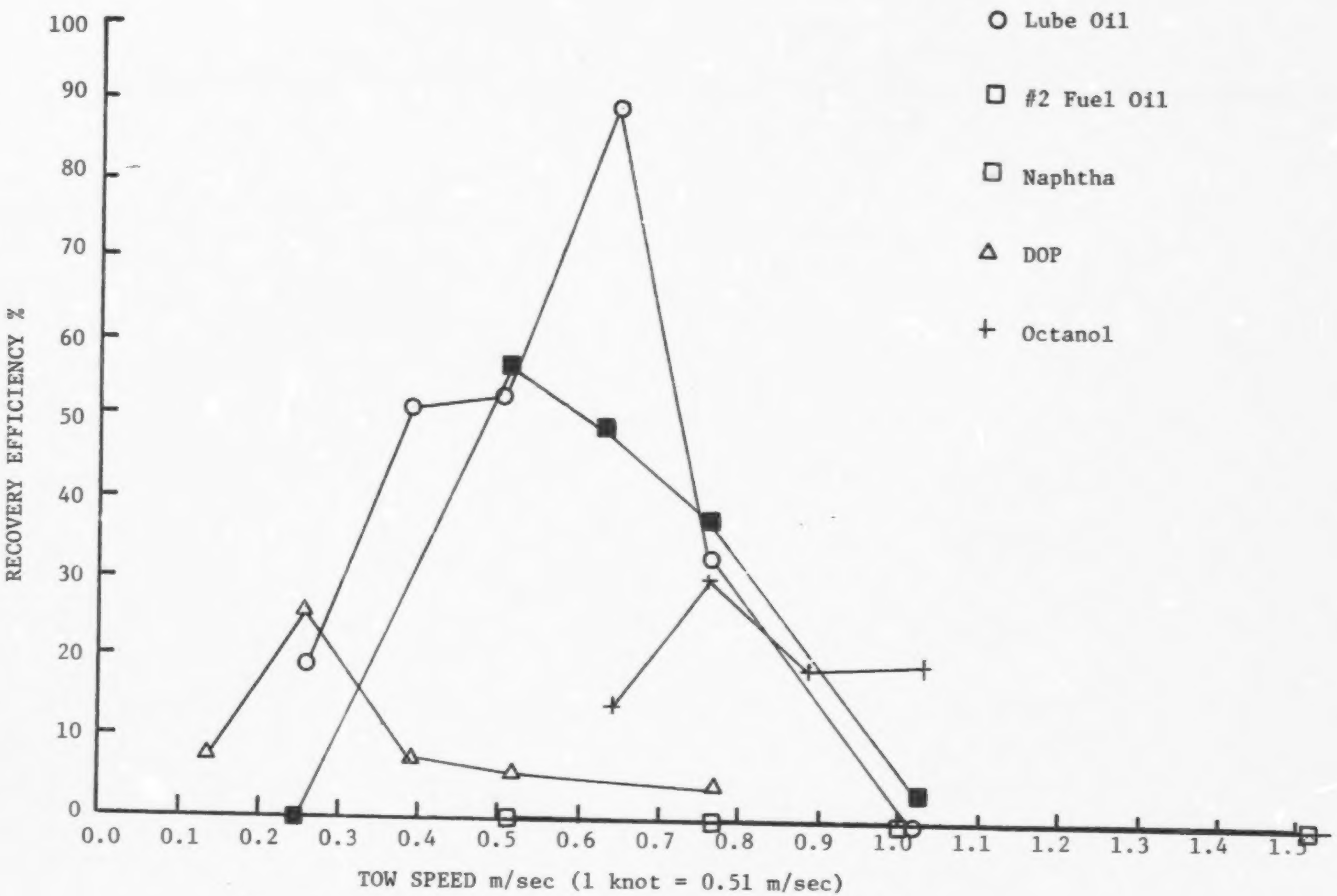

Figure 16. Recovery efficiency vs. tow speed ORS-125.

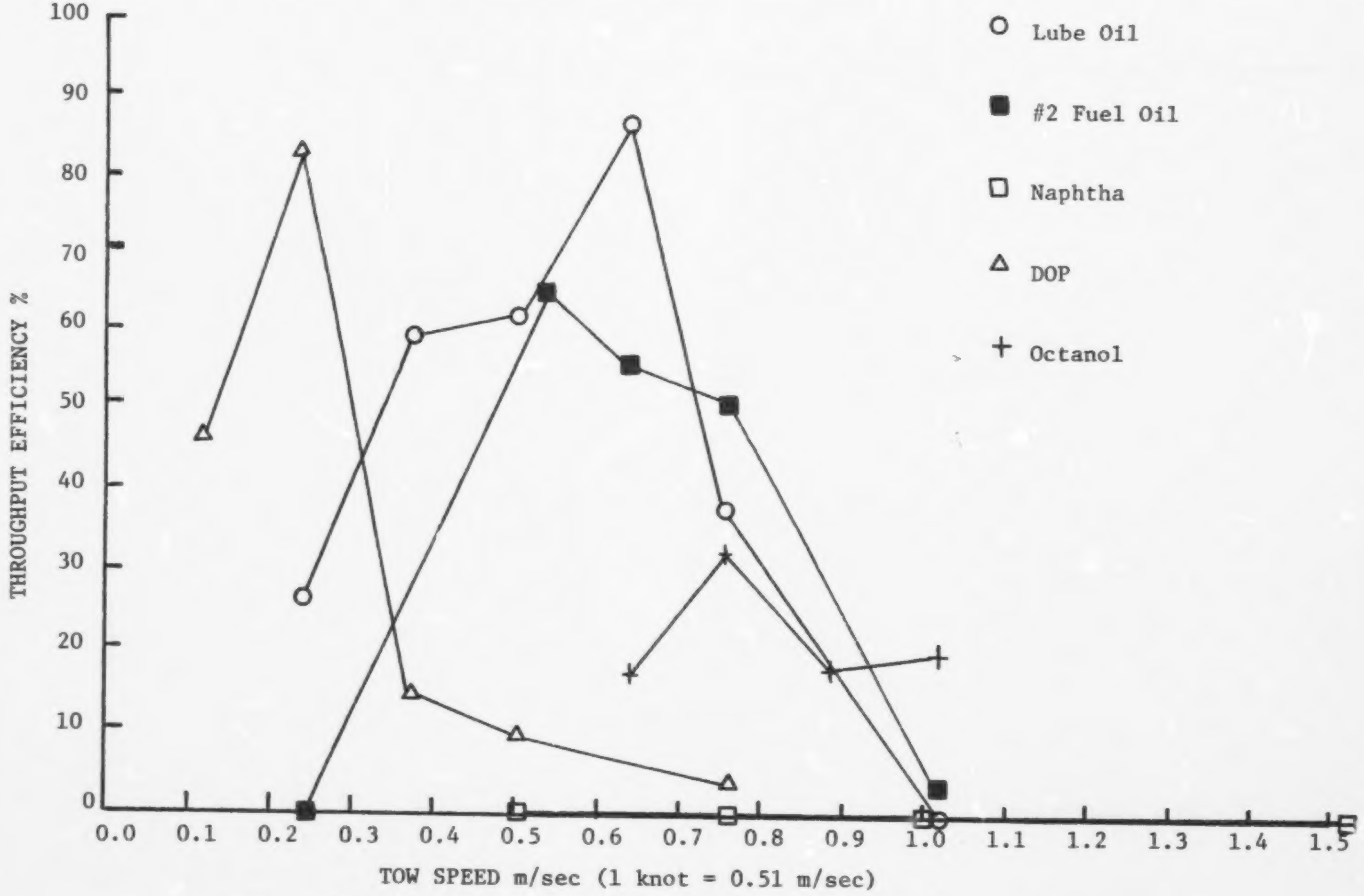

Figure 17. Throughput efficiency vs. tow speed ORS-125.

and consequently, performance under those conditions could vary from these test results.

ADVANCING SKIMMER TEST RESULTS - DISCUSSION

Tabular data results of performance testing are available in Tables 18 and 19. Summary plots of performance parameters vs. controlled conditions (independent variables) are located in Figures 12, 13, 14, 15, 16, and 17, and will be referred to in the following discussion of both skimmers.

The DIP-1002 skimmer was tested with the following controlled settings:

- Belt speed = 1.22 m/s (2.42 kt)
- Tow speed = 0.25 to 1.27 m/s (0.5 to 2.5 kt)
- Notch opening = 1.9 cm (0.75 in)
- Slick width = 1.52 m (5 ft)
- Slick thickness = 2 mm (0.08 in)
- Tank surface condition = calm

HM recovery rate was optimized for each test fluid with respect to increasing tow speed above 0.25 m/s (0.5 kt). The lower density naphtha was best recovered at the relatively high tow speed of 1.14 m/s (2.2 kt). Optimum recovery rate with DOP occurred at the lower tow speed of 0.25 m/s (0.5 kt). These results indicated that the tow speed for optimum performance was dependent upon the density of the HM materials. Except for DOP, the maximum recovery rates of all test fluids were comparable and it is possible that this recovery rate ($\approx 1.3 \times 10^{-3} m^3/s$ (20.6 gal/min)) may have been reached with DOP at tow speeds lower than 0.25 m/s. Since speeds greater than 0.25 m/s are unacceptable for field use conditions, performance at these speeds was not considered of interest to the overall test program.

The following list indicates the monotonic relationship between optimum tow speed (at which maximum recovery rates occurred) and specific gravity:

Optimum Tow Speed	Test Fluid	Specific Gravity
1.14 m/s (2.25 kt)	Naphtha	0.710
0.89 m/s (1.75 kt)	Octanol	0.827
0.63 m/s (1.25 kt)	#2 fuel	0.849
0.63 m/s (1.25 kt)	Lube oil	0.870
0.25 m/s (0.5 kt)	DOP	0.975

Since the intent of the dynamic inclined belt is to induce a flow velocity relative to the test fluid, a critical balance of belt speed to tow speed must be established for each given test fluid. For those fluids that tend to form large diameter droplets upon breakaway (DOP) and have a longer rise time, collection increases at lower current speeds because the droplets must rise into the oil collection well. As tow speed increases, test fluid droplets rise behind the collection well and are drawn through the backplate opening and out behind the device. This was evidenced through performance data as well as visual observation. In the case of the low density Naphtha, it was possible to establish a higher flow velocity and successful collection since the rise time is faster. In fact, higher flow velocities were required to move the test fluid to the collection well.

Throughput efficiency can be analyzed in much the same manner as recovery rate. Optimum efficiencies generally fell within the range of 40-60T with a maximum of 85% when tested with DOP. However, this 85% efficiency occurred at the minimum tow speed of 0.25 m/s (0.5 kt) which is too low for field use consideration.

In the case of the ORS-125, a weir-type advancing skimmer, the following test conditions were established:

- Tow speed = 0.25 to 1.52 m/s (0.5 to 3.0 kt)
- Air supply to onboard pump = 300 x 10^3 N/m^2 (44 psi)
- Slick thickness = 4 mm (0.16 in)
- Slick width = 1.52 m (5 ft)
- Surface condition = calm

Performance was indicated by HM recovery rate, recovery efficiency, and throughput efficiency. A maximum throughput efficiency of 90% occurred when testing with DOP at 0.25 m/s (0.5 kt) and Lube oil at 0.63 m (1.25 kt). When confronted with the low density Naphtha, the device was unable to successfully collect material. The density dependence of the weir-type advancing skimmer was readily observed both visually and quantitatively.

The following list indicates the relationship between optimum tow speed (at which maximum recovery rates occurred) and specific gravity:

Optimum Tow Speed	Test Fluid	Specific Gravity
None	Naphtha	0.710
0.76 m/s (1.5 kt)	Octanol	0.827
0.65 m/s (1.3 kt)	#2 fuel	0.849
0.65 m/s (1.3 kt)	Lube oil	0.870
0.25 m/s (0.5 kt)	DOP	0.975

The ORS-125 was unable to recover Naphtha as shown in Figure 15. Specific gravity appeared to be the most significant variable in that the thickness of HM between the primary and secondary weirs depends on a balance bewteen buoyancy forces and momentum forces at a given tow speed. Naphtha, being very buoyant did not thicken at tow speeds up to the ORS-125 maximum stable tow speed (1.5 m/s) before submarining. Table 19 shows this as the headwave continued to grow outward from the device (4.3 to 1.8 m) as compared to tests with DOP where the headwave was closer to the primary weir (1.2 to 0.0 m) with good recovery rates.

COMMENTS

Observing the red color of the discharge stream during tests conducted with octanol, it appeared that the percentage of HM in the stream varied during steady state data collection (see tests 11 and 12). To improve this steady state variation, two methods were employed:

a. Sampling recovery during two 30 s periods of the recovery, and averaging recovery parameters. Take for example test 11 where the total steady state time was 60 seconds:

   1. First 30 s sample:

      Volume octanol recovered = 0.02 m^3 (5.3 gal)

      Recovery efficiency = 13.1%

      Octanol recovery rate = 0.8×10^{-3} m^3/s (12.6 gpm)

   2. Second 30 s sample:

      Volume octanol recovered = 0.05 m^3 (13.2 gal)

      Recovery efficiency = 26.9%

      Octanol recovery rate = 1.6×10^{-3} m^3/s (25.4 gpm)

      Average octanol recovery rate = 1.2×10^{-3} m^3/s (19.0 gpm)

      Average recovery efficiency = 20%

   For the total test run, the recovery rate was 1.2×10^{-3} m^3/s and recovery efficiency was 20%.

b. An attempt was made to preload the ORS-125; however, variation in the color of the discharge stream during steady state recovery persisted.

One general operation result from these tests is the ORS-125 weir-type skimmer probably could not be used effectively to recover HM slicks of specific gravity less than or equal to 0.710 unless modified to overcome the operational problem indicated here.

SECTION 9

SORBENT SYSTEM TESTS

SORBENT SYSTEM TEST PROCEDURE

The sorbent system involved the deployment of three separate units. The broadcaster was positioned on the bridge with a sorbent supply operator and broadcaster operator. The harvester was positioned on a catamaran type floatation frame, with containment booms in a V-shaped configuration that diverted the slick towards the harvester (Figure 18). For each test, a technician set and maintained the belt speed of the harvester, timed recovery of the sorbent material and sampled recovered sorbent cubes. The regenerator was positioned off the OHMSETT tank; a regenerator operator collected samples of sorbent material for the calculation of density data.

Performance testing began after all personnel and devices were positioned, and desired surface conditions, tow speed and HM distribution had been initiated. Sorbent material was broadcast when the test fluid appeared at the trailing end of the bridge. The sorbent material was recovered and dropped into a hopper on the back of the harvester; the period was timed from collection of the first cube to the last. The hopper was then removed by a crane, and the sorbent material weighed and brought to the regenerator. The sorbent material was then passed through the regenerator for removal of the HM; total fluid recovered and the HM portion were then measured.

A step-by-step test procedure for the sorbent system is given below in the following format: Manpower Allocations, Pre-test Checklist, Test Sequence, Data Sheets, and Data Analysis.

Manpower Allocations

The following allocations of duties were made:

1. Test director - responsible for running the tests according to the prescribed test matrix and test procedure. Manages the test personnel.

2. Control room operator - operates the wave generator and collects the data for ambient conditions.

3. Fluids dispensing operator - maintains the test fluid thickness at 2.54 cm at the beginning of each run. Assists with other duties as needed.

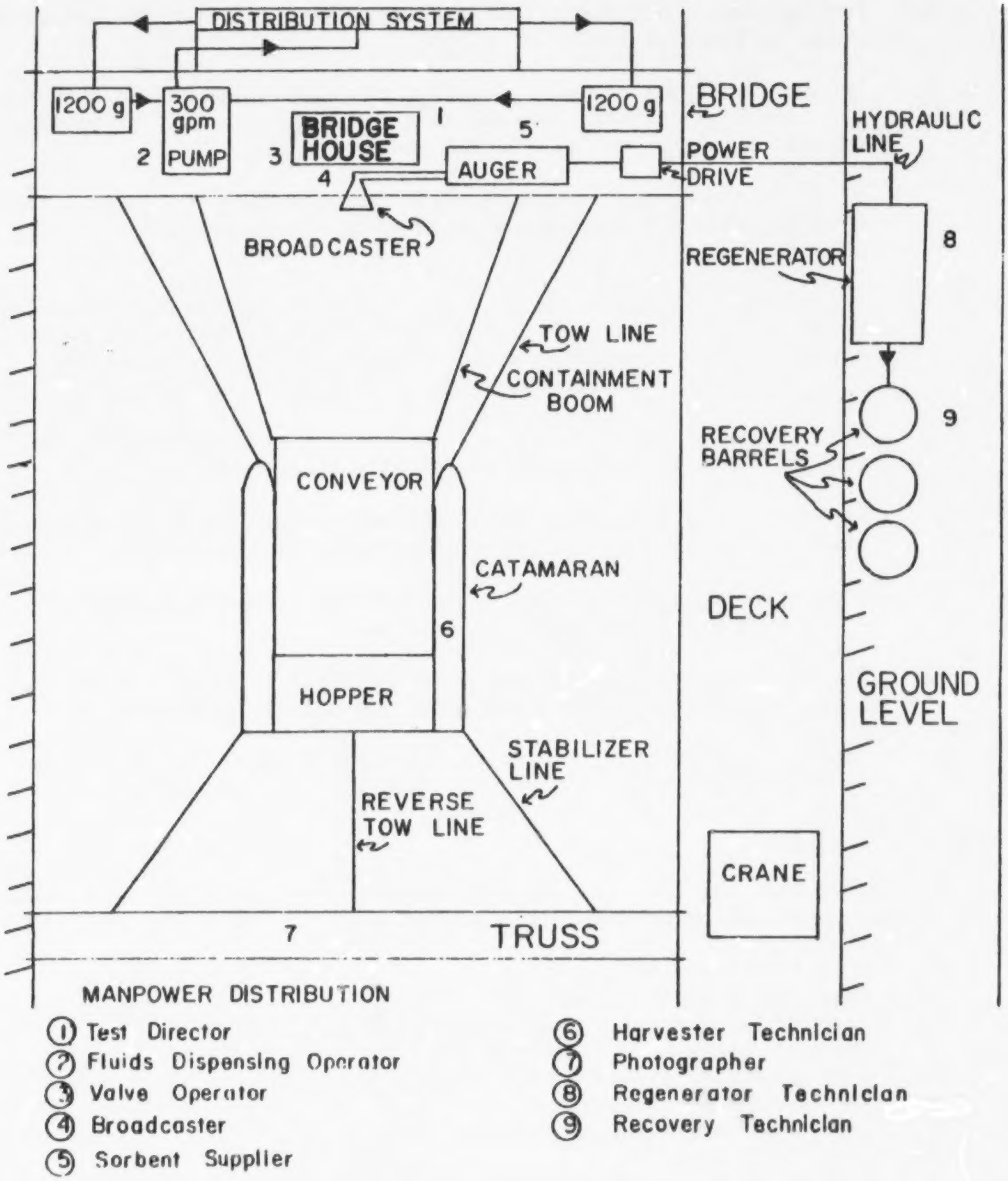

Figure 18. Sorbent system test details.

4. Data documentation officer - observes and records test fluid collection data and keeps a notebook of performance observations. Performs the analysis and reduction of all data.

5. Photographer - documents the test with 35 mm color slides and 16 mm color motion pictures.

6. Chemical analysis officer - samples the test fluid before and after the test run. Samples are analyzed for water content, viscosity, specific gravity and interfacial tension.

7. Fluids clean-up team leader - heads the operation of cleaning the residual test fluid from the water surface in preparation for the next test run.

8. Fluids refurbishment team leader - heads the operation of removing water (both free and emulsified) and contaminants from the test fluid prior to its reuse. Also, responsible for operating the D.E. filter unit to maintain tank water purity and clarity.

9. Power drive operator - sets and maintains the required screw setting to establish the distribution of sorbent material.

10. Sorbent supply operator - feeds the appropriate amount of sorbent material to the screw to ensure continuous distribution.

11. Sorbent broadcaster operator - distributes sorbent material on surface of water for length of test run.

12. Harvester operator - sets and maintains belt speed of harvester, times recovery of sorbent material, and samples recovered sorbent.

13. Regenerator operator - operates regenerator and collects samples of sorbent material for the calculation of density data.

Pre-test Checklist

To ensure that all test systems and equipment were maintained and ready for the test, the following checklist was used prior to the first test run:

1. D.E. filter system operating
2. Chlorine generator operating
3. Air-bubbler barrier system operating
4. Bridge drive system operating
5. Wave generator system operational
6. Test device operational
7. Test instrumentation operational
8. Test fluid ready
9. Test fluid distribution system operational
10. Test support equipment operational
11. Photographic systems ready
12. Test personnel prepared and ready
13. Complete all pre-run data sheets and checklists

Test Sequence

The following test sequence was used for the sorbent recovery system:

1. Position the traveling bridge and test device for testing (see Figure 18).

2. Position all test personnel for testing (see Figure 18).

3. Inform all test personnel of test conditions take from the test matrix.

4. Calibrate the flow rate using the recirculation mode, and continue to recirculate while observing test fluid temperature and pressure drop. Just prior to test run, take sample of recirculating test fluid and record test fluid temperature.

5. Calibrate the screw setting by adjusting the power drive with a strobe light to 40 rpm, and adjust belt speed on harvester.

6. Give three (3) blasts on the air horn to clear the tank decks, alert all test personnel of test run, and start the wave generator, if required.

7. Using either intercom system or walkie-talkies, begin countdown from five (5), with the control room operator to begin bridge motion at zero (0) and one (1) blast on the air horn.

8. One (1) blast on the air horn initiates the following: start bridge, start test fluid distribution, and start stopwatches.

9. Control room operator informs test director of steady state bridge speed.

10. Commence broadcasting of sorbent when test fluid appears at trailing edge of bridge.

11. Recover sorbent and catch in hopper, and time period from collection of first cube to last cube.

12. Test fluid distribution ceases after 1.32 m^3 (350 gal) is distributed and distribution time is recorded.

13. Cease sorbent broadcasting when end of test fluid slick is reached.

14. Test director begins countdown from five (5) to stop the bridge and wave generator.

15. Lower the bridge "skimming plate" to prevent the test fluid from passing under the bridge and to skim all residual test fluid back to the north end surface containment area.

16. Remove hopper from catamaran with crane, weigh recovered sorbent and move hopper to generator.

17. Connect hydraulic hoses from power drive to regenerator and distribute recovered sorbent from hopper to regenerator belt.

18. Sample regenerated sorbent material and measure the total fluid recovered and test fluid recovered.

19. Return the hopper to catamaran and prepare for next test run.

Data Sheets

The following data sheets were used for the sorbent system tests:

1. Test Equipment Characteristics and Rigging Configuration
2. Chemistry Laboratory Analysis
3. Ambient Conditions Data Sheet
4. Broadcaster Data Sheet
5. Harvester Data Sheet
6. Regenerator Data Sheet
7. Sorbent System Summary Data Sheet

Data Analysis

The data documentation officer performs all data analysis and reduction. All data sheets are submitted to him for compilation onto master raw data sheets as shown in Table 20. The ultimate responsibility for proper data collection, analysis and presentation belongs to the OHMSETT Project Engineer. He writes the final report and disseminates data to the EPA Project Officer.

TEST DATA

Table 20 contains information of the test fluid properties, ambient conditions, and wave characteristics at the time the sorbent system was tested. It should be noted that there was a 21 second delay between the time the broadcaster distributed the polyurethane cubes onto the slick and the time the cubes encountered the harvester. This 21 second delay has been incorporated into the total test time. The recovery rate lists the rate at which the equipment recovers the HM/water mixture under test conditions. Throughput efficiency is the percentage of HM recovered to the amount encountered by the sorbent system. Recovery efficiency is the percentage of HM recovered in the total mix (% test fluid).

SORBENT SYSTEM TEST - DISCUSSION

The throughput efficiencies for the sorbent system, with a fixed tow speed of 1.02 m/s (2.0 kt), were quantitatively noted as being somewhat independent of test fluid property (see Figure 21). Also, the device when subjected to "random" wave surface conditions maintained a high throughput efficiency of between 60 and 80%. As in the results of the oleophilic rope, the effects of natural hydrodynamic forces which tend to cause high density materials to become entrained were reduced. The absorption rate of the sorbent material for various test fluids played an important role in effective spill removal. The sorbent system tested utilized polyurethane open-celled foam which absorbed the HM rapidly and was easily regenerated. Recovery efficiency was maximized at 80% in the no wave condition with Naphtha, with and without waves. Performance is graphically presented in Figures 19, 20, and 21.

Recovery rate was optimized with octanol and was even higher with the 0.6 m harbor chop at OHMSETT. However, the experimental determination of recovery rate was not as accurate as for throughput and recovery efficiencies.

Most of the problems encountered were equipment related. Sorbent cubes could not be broadcasted at high enough volumetric rates without plugging up the broadcaster and suffering non-uniform distribution. Also, the regenerator was difficult to use and did not always uniformly squeeze-dry the cubes. This was due to several problems. First, there was no mechanism for uniformly feeding in the saturated cubes; thus cubes non-uniformly distributed across and along the belt. Then belt slippage from side to side and on the rollers caused considerable problems. Another point for consideration is this: even though the cubes are squeezed enough to move the HM from top to bottom of the cubes, a certain amount of residence time is required for gravitational forces to break it loose and into the recovery tank. Observations indicated more residence time was needed for the more viscous HM (i.e. DOP, Lube oil) or the unit could be redesigned to include air jets to assist by blowing it loose and into the recovery tank.

TABLE 20. TEST RESULTS SEAWARD SORBENT SYSTEM.

DATE	TIME	TEST NUMBER	TEST FLUIDS PROPERTIES						AMBIENT CONDITIONS			WAVE CHARACTERISTICS			FLUID DISTRIBUTION VOLUME m^3	SORBENT DENSITY		TEST EQUIPMENT SETTINGS				PERFORMANCE CHARACTERISTICS		
			TYPE	TEMPERATURE °C	VISCOSITY m^2/sec. x 10^{-6}	SURFACE TENSION N/m x 10^{-3}	INTERFACIAL N/m x 10^{-3}	SPECIFIC GRAVITY	AIR TEMPERATURE °C	WIND SPEED m/sec.	WIND DIRECTION	HEIGHT meters	LENGTH meters	PERIOD sec.		RECOVERED kg/m^3	REGENERATED kg/m^3	BROADCAST RATE m^3/sec. x 10^{-2}	BROADCAST VOLUME m^3	HARVESTER BELT SPEED m/sec.	REGENERATOR TENSION PRESSURE N/m^2 x 10^5	RECOVERY RATE m^3/sec. x 10^{-1}	% TEST FLUID	THRUPUT EFFICIENCY
9/16	0910	1	DOP	18.9	78.8	30.6	10.7	.9860	20.0	2.2	SE	0	0		0.10	603.4	116.5	0.47	0.20	1.04	2.01	1.30	73.1	65.6
9/16	1030	P1	DOP	18.9	78.8	30.6	10.7	.9860	20.0	2.2	SE	0.3	HC		0.17	592.4	116.6	0.54	0.24	1.04	2.14	1.72	72.6	73.7
9/16	1130	P2	DOP	18.9	78.8	30.6	10.7	.9860	23.3	2.7	E	0.3	HC		0.17	733.2	101.4	0.36	0.20	1.04	2.24	1.69	86.3	62.4
9/16	1430	P3	DOP	18.9	78.8	30.6	10.7	.9860	22.2	2.7	E	0.3	HC		0.09	737.7	171.6	0.28	0.07	1.04	2.21	0.75	46.3	16.7
9/16	1530	P4	DOP	18.9	78.8	30.6	10.7	.9860	22.2	2.2	E	0.3	HC		0.15	692.3	121.7	0.41	0.24	1.04	2.14	1.57	87.2	77.8
9/17	0920	P5	DOP	18.9	78.8	30.6	10.7	.9860	17.8	0.9	S		RUN	ABORTED										
9/17	1055	P6	DOP	18.9	78.8	30.6	10.7	.9860	18.9	0.9	E	0.3	HC		0.12	841.6	145.9	0.29	0.17	1.04	2.07	1.44	79.9	76.5
9/17	1250	2a	DOP	18.9	78.8	30.6	10.7	.9860	22.2	2.2	E	0.6	HC		0.13	595.1	155.5	0.49	0.29	1.04	2.07	1.54	76.5	79.1
9/17	1345	2b	DOP	18.9	78.8	30.6	10.7	.9860	23.3	1.3	E	0.6	HC		0.12	728.4	137.8	0.36	0.19	1.04	2.07	1.42	74.3	68.0
9/18	0950	7	NAP	20.0	6.5	23.8	18.0	.7705	20.0	4.5	E		0		0.14	663.0	144.3	0.32	0.19	1.04	2.34	1.44	85.9	75.4
9/18	1105	8	NAP	20.0	6.5	23.8	18.0	.7705	20.0	6.3	NE	0.6	HC		0.13	566.3	152.8	0.34	0.20	1.04	2.34	1.21	77.2	60.2
9/18	1200	6a	NAP	20.0	6.5	23.8	18.0	.7705	22.2	5.4	NE	0.3	HC		0.13	549.3	123.2	0.34	0.20	1.04	2.41	1.35	87.6	72.3

(Continued)

TABLE 20. (Continued)

DATE	TIME	TEST NUMBER	TEST FLUIDS PROPERTIES						AMBIENT CONDITIONS			WAVE CHARACTERISTICS			FLUID DISTRIBUTION VOLUME m^3	SORBENT DENSITY		TEST EQUIPMENT SETTINGS				PERFORMANCE CHARACTERISTICS		
			TYPE	TEMPERATURE °C	VISCOSITY $m^2/sec. \times 10^{-6}$	SURFACE TENSION $N/m \times 10^{-3}$	INTERFACIAL $N/m \times 10^{-3}$	SPECIFIC GRAVITY	AIR TEMPERATURE °C	WIND SPEED m/sec.	WIND DIRECTION	HEIGHT meters	LENGTH meters	PERIOD sec.		RECOVERED kg/m^3	REGENERATED kg/m^3	BROADCAST RATE $m^3/sec. \times 10^{-2}$	BROADCAST VOLUME m^3	HARVESTER BELT SPEED m/sec.	REGENERATOR TENSION PRESSURE $N/m^2 \times 10^6$	RECOVERY RATE $m^3/sec. \times 10^{-3}$	% TEST FLUID	THRUPUT EFFICIENCY
9/18	1340	6h	NAP	20.0	6.5	23.8	18.0	.7705	22.2	6.7	NE	0.3	HC		0.12	634.3	144.6	0.26	0.14	1.04	2.24	1.07	90.1	61.0
9/19	0920	4	OCT	20.0	12.4	26.2	7.6	.8358	20.0	3.6	S	0	0		0.13	866.3	166.0	0.40	0.22	1.04	2.41	2.03	48.6	62.0
9/19	1255	3R	OCT	20.0	12.4	26.2	7.6	.8358	24.4	3.6	NE	0.6	HC		0.13	777.2	132.8	0.46	0.30	1.04	2.59	2.18	40.1	57.5
9/19	1350	5	OCT	20.0	12.4	26.2	7.6	.8358	24.4	1.8	N	0.3	HC		0.11	854.3	156.7	0.34	0.20	1.04	2.41	1.73	50.9	69.6

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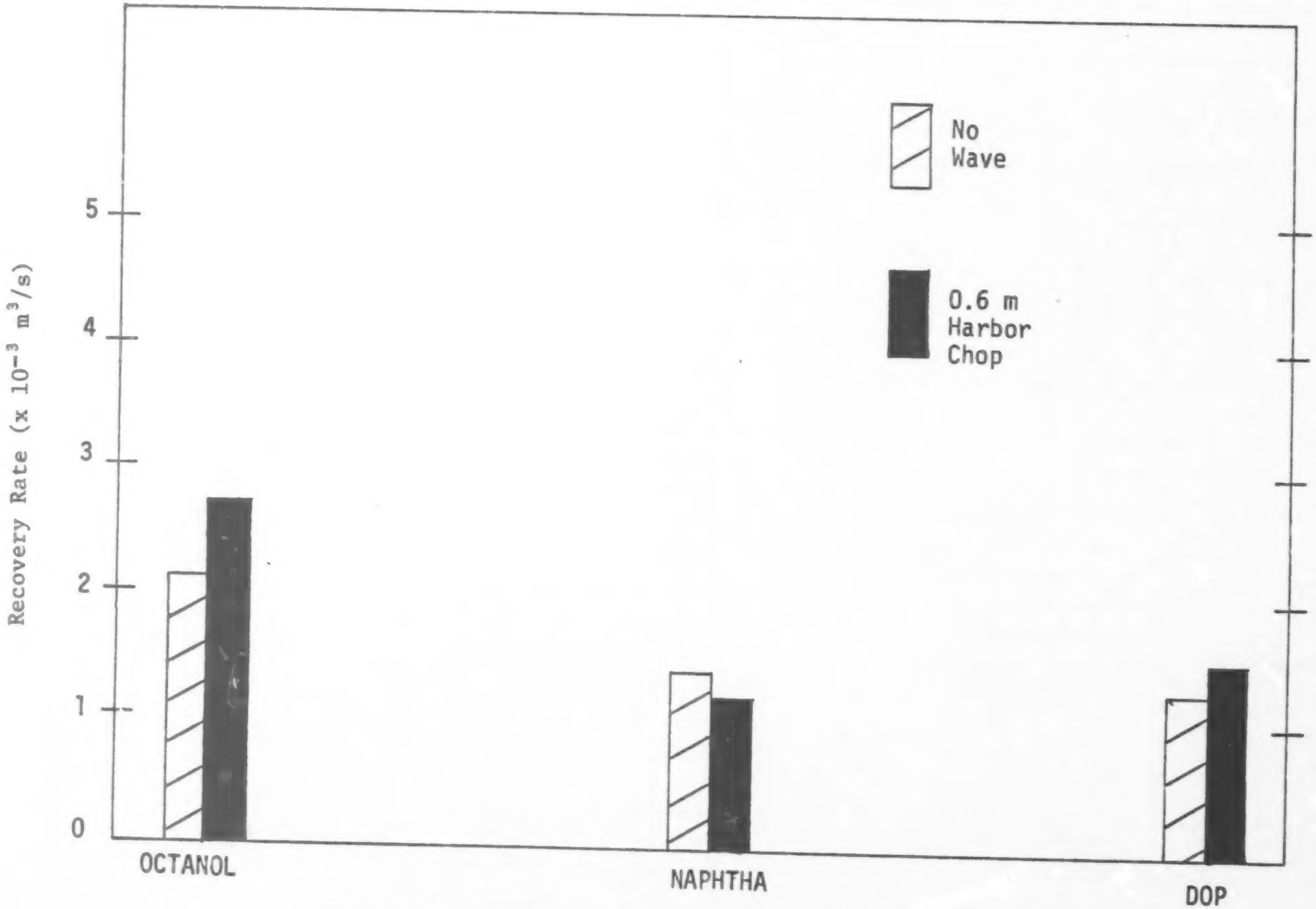

Figure 19. Recovery rate of the Seaward sorbent system.

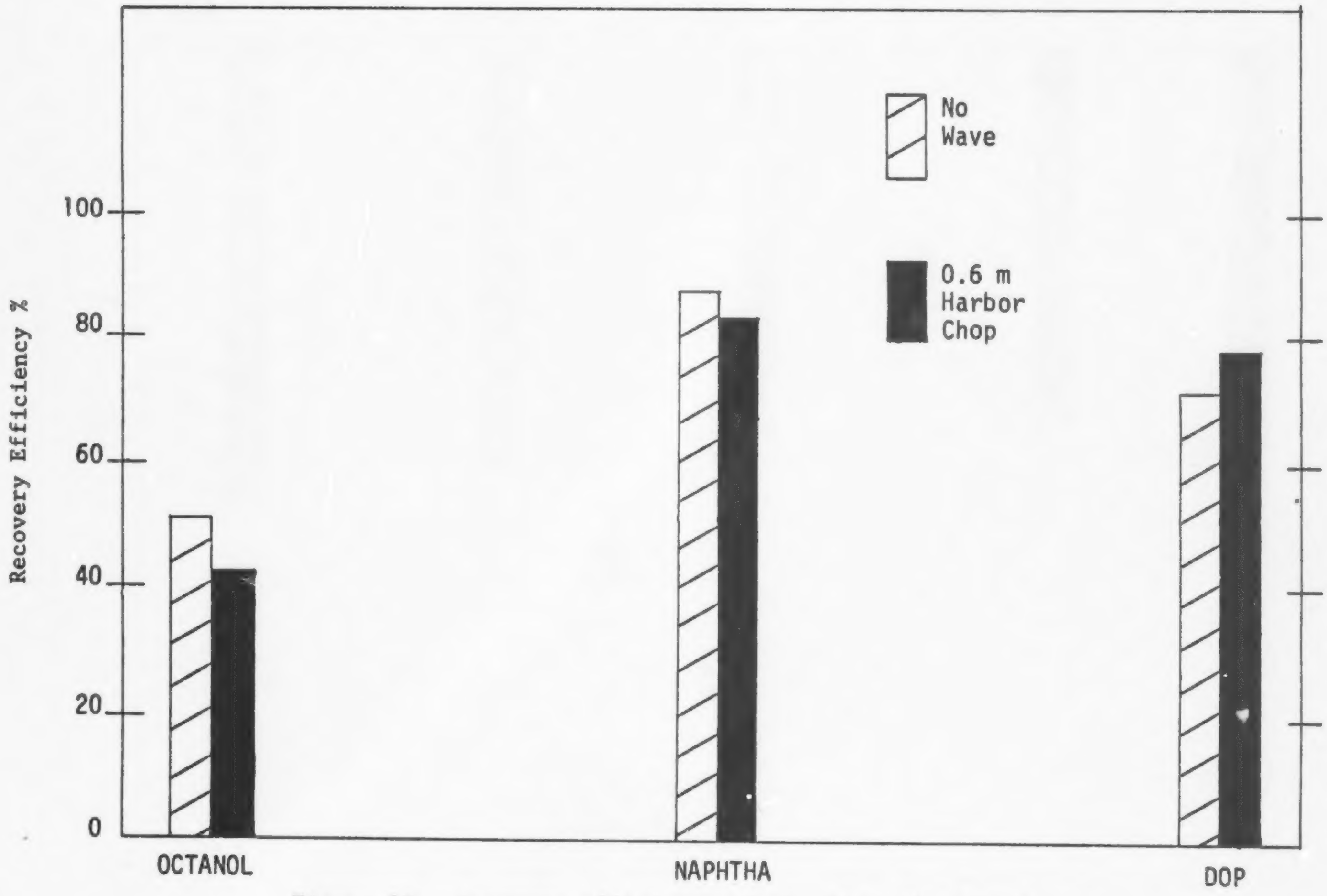

Figure 20. Recovery efficiency of the Seaward sorbent system.

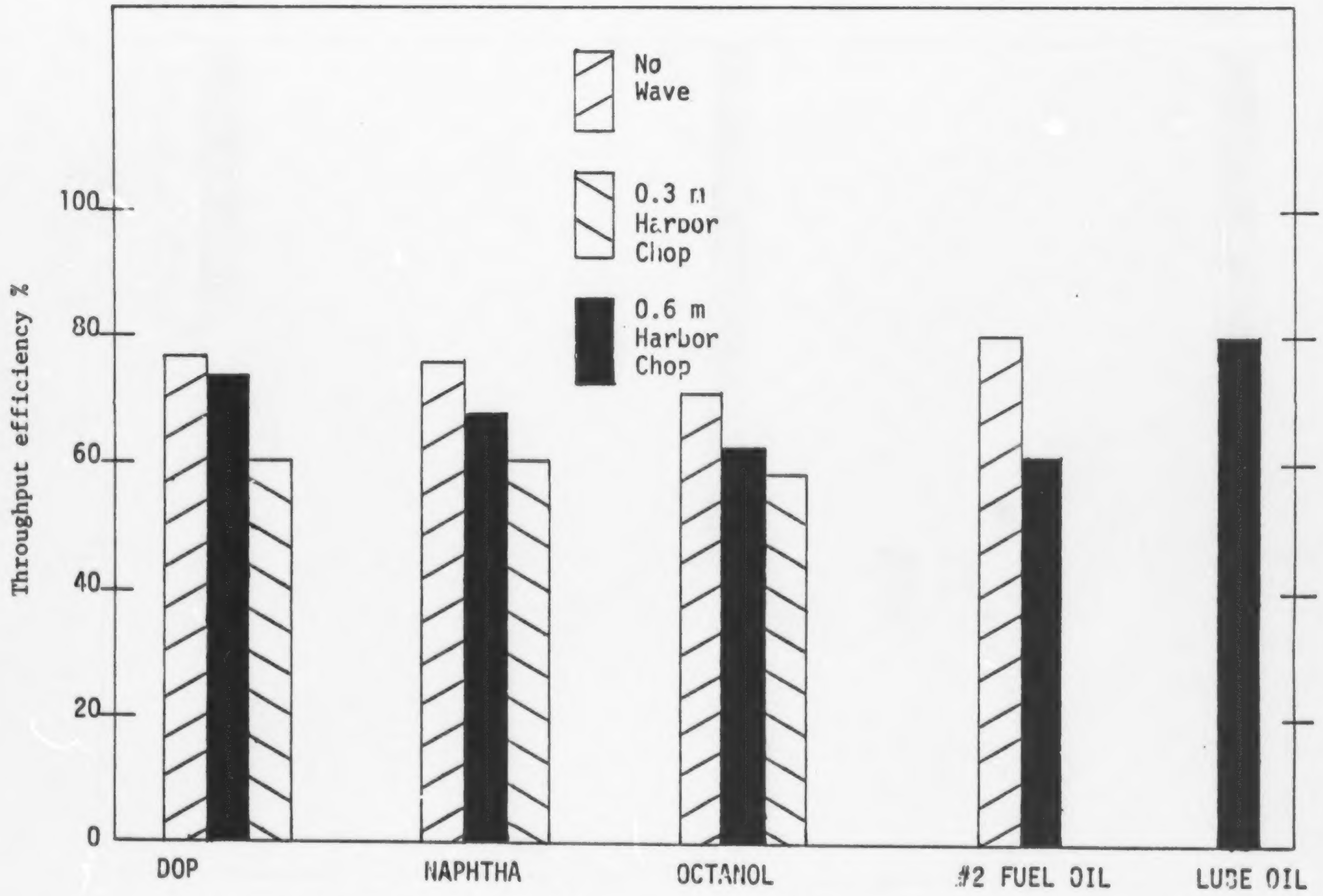

Figure 21. Throughput efficiency of the Seaward sorbent system.

SECTION 10

INTERPRETATION AND USE OF TEST RESULTS

STATISTICS

Repeatability

Full-scale testing in a controllable environment such as OHMSETT offers tremendous advantages over field testing. Probably the most significant advantage is that each component of testing is controllable within certain statistically definable limitations.

For this program the following statistical parameters were calculated based upon replicate testing:

1. Mean
2. Variance
3. Standard Deviation
4. 95% Confidence Interval
5. 90% Confidence Interval
6. Coefficient of variation - a non-dimensional measure of percent dispersion from the mean defined by the following equation:

$$\frac{\text{standard deviation}}{\text{mean}} \times 100\%$$

Statistical Evaluation of the DIP-1002

Repeat tests were limited to three performance runs, with the DIP encountering octanol at a velocity of 0.63 m/s.

Test No.	Octanol Recovery Rate (x 10^{-4} m^3/s)
3a	6.1 (9.7 gpm)
3b	7.1 (11.3 gpm)
3c	8.3 (13.2 gpm)

Mean octanol recovery rate = $\bar{x} = 7.2 \times 10^{-4}$ m^3/s (11.4 gpm)
Variance = $\sigma^2 = 1.213 \times 10^{-8}$
Standard Deviation = $\sigma = 1.102 \times 10^{-4}$ m^3/s
95% Confidence Interval = $\pm$ 3.4 x 10^{-4} m^3/s (5.4 gpm)
90% Confidence Interval = $\pm$ 2.3 x 10^{-4} m^3/s (3.6 gpm)
Coefficient of Variation = $\sigma/\bar{x}$ = 15.3%

Statistical Evaluation of the ORS-125

Based upon the results of tests P1 through P5 the following calculations were performed:

Test No.	DOP Recovery Rate (x 10^{-3} m^3/s)
P1	1.3 (20.6 gpm)
P2	1.4 (22.2 gpm)
P3	1.4 (22.2 gpm)
P4	1.5 (23.8 gpm)
P5	1.1 (17.5 gpm)

Mean DOP recovery rate = $\bar{x} = 1.34 \times 10^{-3} m^3/s$ (21.3 gpm)
Variance = $\sigma^2 = 0.0230 \times 10^{-6}$
Standard Deviation $= \sigma = 0.1517 \times 10^{-3}$ m^3/s
95% Confidence Interval = $\pm$ 0.20×10^{-3} m^3/s (3.2 gpm)
Coefficient of Variation = $\sigma/\bar{x}$ = 11.3%

Further statistical analysis is available in Table 21.

TABLE 21. STATISTICAL DATA.

Device	Number of repeat tests	Mean HM recovery rate $m^3/s \times 10^{-3}$ (gpm)	Variance	Standard deviation $m^3/s \times 10^{-3}$	95% Confidence level $m^3/s \times 10^{-3}$	Coefficient of variation (%)
Seaward Sorbent System	14*	1.10 (15.8)	0.034	0.19	±0.10	17.3
DIP-1002	3	0.72 (11.4)	0.012	0.11	±0.12	15.3
ORS-125	5	1.33 (21.1)	0.021	0.14	±0.12	11.3
Slickbar Mantaray	6	1.45 (23.0)	0.059	0.25	±0.19	16.6
Oil Mop	4*	0.69 (11.0)	0.004	0.06	±0.06	8.7
OELA	5*	1.28 (20.3)	0.016	0.13	±0.11	10.2

*Not repeats of a given test condition-- includes all test conditions, since performance appeared to be independent of the test condition.

Precision and Accuracy

The precision of the testing was defined through a repetition of selected runs, and a comparison of the resulting data. In general, the repeated tests showed a calculated dispersion (i.e., coefficient of variation) from the mean performance level of $\leq$ 17%, depending upon the type of equipment tested and the number of test repeats. The ORS-125 test device produced the lowest dispersion of 11% with five test repeats. For barriers, the speed at which no loss occurs is a somewhat subjective determination; therefore, the validity of precision data is observer-related. Detailed analysis of the repeated test runs are given in Table 21.

The question of the accuracy of tank testing (the correlation of tank testing, field testing and field use) deserves consideration. These tests were conducted under controlled conditions in a facility specifically designed for such testing. All testing was full-scale, and every effort was made to have maximum control over each test parameter. There are effects associated with controlled-condition testing, however, that distinguish the test environment from the field environment. Examples of these effects are the cross-currents in the tank that are caused by the bubbler system (designed to keep test fluids off the walls and away from the beach and wave generator), and the difference between the uniform velocity profile of the tank (relative to a test device) and the profile of a river (Figures 22, 23). Further, wave profiles that are generated are subject to influence by the shallow tank (2.44 m (8 ft deep)) and some reflections from the absorber beach. The waves and currents generated in OHMSETT therefore are simulations of conditions encountered in the real environment, rather than actual reproductions of those conditions. Actual performance of equipment during spill situations may therefore vary from the results reported from OHMSETT testing. Test results are, therefore, to be considered as a guide or an estimate of performance to be expected.

OBSERVATIONAL RESULTS

Certain insights can be drawn from the observation (both above and below the water suface) of more than 1,000 individual tests on a wide variety of equipment, over a variety of conditions of waves and current, and with test fluids (both oils and HM) having wide ranges of viscosity, specific gravity differential with water, and interfacial tension.

The performance of spill control equipment in waves and currents is apparently limited by the complex interaction of the device with the spilled fluid and the water. The nature of this interaction is remarkedly similar among all of the devices observed, and is apparently a function of two zones of interaction.

The first zone of interaction is that of the water and the device. Consider any spill control device having a displacement or blockage of the water and relative motion with the water. The flow of water around the device is different from the pattern without the device present. This changed pattern can be described as waves and turbulence in the vicinity of the device. If the device has a tendency to cause the spilled fluid to slow or stop relative to the water, the spilled fluid itself becomes part of the blockage of the water, and further contributes to the pattern of turbulence in the water. If waves are superimposed upon the current conditions, the device moves relative to the waves in motions called pitch, roll, yaw, heave, sway and surge. These wave-induced motions contribute still more to the complexity of the motion of the water around the device.

The second zone of interaction is that of the water and the spill fluid in or entering the control zone of the device. Consider the floating device as the frame of reference with complex water motions around it. Further consider that each device has a particular zone or volume with the function of spill control. The spilled fluid must reach this control zone and remain there long enough to be acted upon--to be adsorbed onto an oleophilic surface or guided to a collection zone, to name a few examples. In each case, the water motion relative to the fluid in or near the control zone of the device has two effects: first, to form fluid droplets which are propelled beneath the surface; and second, to entrain those droplets in the water moving around the device in such a manner that the droplets do not reach the control zone of the device, but rather are swept past it.

Droplet behavior is really a description of the ability of the device to hold the spilled fluid in the control zone long enough for beneficial results. The manner in which the fluid is removed from the control zone, and the subsequent handling (internal to the control device) of the fluid and any associated water, have significant bearing on the overall performance of the device. But the most elemental problem of spill control in currents and waves is to cause the spill fluid to enter and stay in the control zone.

It seems desirable, then, to quantify the nature of water flow relative to a given device and relative to the fluid contained in its control zone. If an adequate means can be found to describe the conditions of turbulence which lead to droplet formation and subsequent entrainment, it will be known quantitatively what to achieve and avoid in the design of equipment. Given a means of measuring and quantifying such turbulence, the performance of equipment could be estimated with reasonable accuracy through hydrodynamic testing alone, without oils. It is possible that the limiting conditions of turbulence which form or entrain droplets can be achieved with numerous possible combinations of currents, wave heights, and wave-steepness ratios. If these limiting conditions can be clearly defined by testing with oil, field tests could be conducted (under conditions which cannot be duplicated in a testing facility) to establish those other environmental conditions that lead to the limiting values of turbulence.

These measurments of tubluence could form a correlation factor between field testing and tank testing, and also the common denominator for all equipment performance testing. A device could then be described in terms of its limiting values of turbulence, and definitions of the conditions of currents and waves leading to those levels of turbulence for that device. At present, no such correlation factor exists, and tank testing only approximates field conditions. Further, results reported from field testing are presently not really suitable for forming a description of the actual conditions, in terms of fluid motions that lead to the particular results.

OPERABILITY RANGES

One very important application of performance test data from OHMSETT is to relate the simulated environmental conditions and the measured performance of the test equipment. Aside from wind effects, which are usually considered of secondary importance relative to waves and currents, most waterway environments can be simulated quite adequately. With the OHMSETT capability to vary wave height (0 to 0.91 m (3 ft)), period (0 to 6 s) and steepness ratio (0.5 to 0.005) in a continuous fashion with wave flap rpm control, and to vary t ow speed or simulated current (0 to 3.05 m/s ± 0.05 (6 kt)), environmental conditions can be closely correlated with performance, and upper limits can be closely defined where performance drops off and becomes unacceptable.

If this definition of operability range were accomplished for all types of spill control and clean up equipment, both the potential user and equipment manufacturer would benefit greatly. The user would know precisely what type of equipment is needed for the environmental conditions in which the equipment is intended to be used, without personally experimenting with elaborate and expensive equipment. The manufacturer would benefit by better knowing how to design equipment to perform in various environments; the specifications and guarantees on equipment, if closely correlated, would result in satisfied customers and improved business.

TEST TANK EFFECTS ON DATA

Test tanks can only approximate the actual waterways. There is no true current (except with flumes), and the waves are affected by the finite depth. Though a separate report would be needed to rigorously define all of the differences, the primary ones are that the waves are mechanically generated, shallow-water waves, and the currents are simulated by relative motion of the traveling bridge with respect to motionless water. Also, there are air generated currents from an air barrier system which lies along the bottom periphery of the tank.

Perhaps the best way to describe the difference in water current profile is to illustrate it for a test tank and a typical river (Figures 22 and 23). For rivers with very steep banks, the surface velocity profile becomes nearly flat, which is true for some cases. However, for most cases, when the diversionary technique is being applied, the very reason for setting the boom at a smaller angle with the mid-stream current is to avoid direct encounter with currents greater than a 0.51 m/s (1 kt) that would cause fluid loss (entrainment). Ideally, the fast mid-stream currents are used to divert oil or HM to the much lower current zone near the shoreline. When testing this concept in the test tank, obviously, there is no slow current zone. The bridge moves with respect to the tank water, and this relative velocity is absolutely the same all across the tank.

How does this affect the correlation of diversionary boom performance in the test tank and the real world? Boom failure inadvertently occurred at the trailing end which was angled the most against the current and should

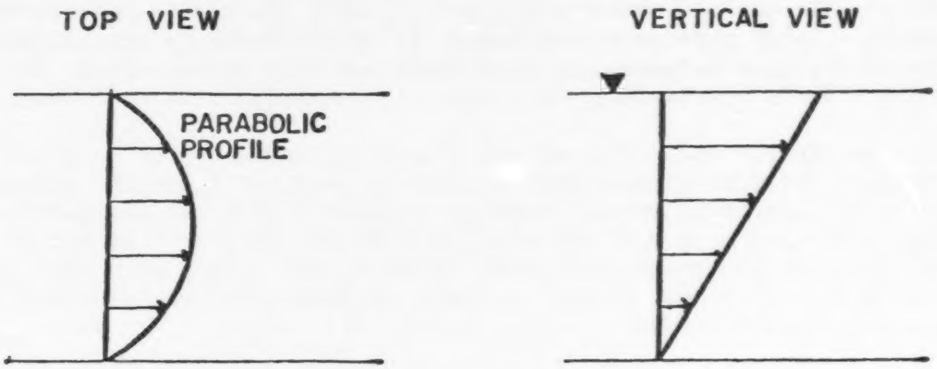

Figure 22. River relative velocity profiles.

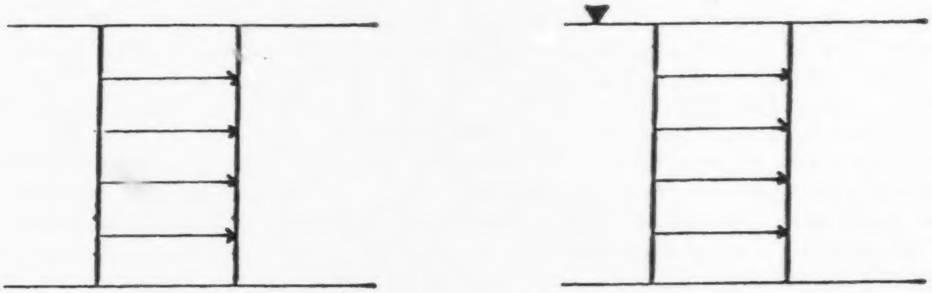

Figure 23. Test tank relative velocity profiles.

have been in the quiet zone (which does not exist in a test tank). If a quiet zone did exist near the test tank wall (or trailing edge of the boom), the "no HM loss" test speed would have increased and been in closer agreement with actual performance in waterways with parabolic surface velocity profiles and quiet zones. The result is that the diversionary "no HM loss" speeds are low and conservative.

The mechanically drive waves in the test tank are categorized as shallow-water waves since the 2.4 m water depth (8 ft) never exceeds the wave length capabilities of the wave generator. The significance of this is twofold: (1) For wind driven waves on deep inland waterways, the reproducibility of the wave generator will not be as close as with shallow-water waves, and (2) The turbulent effects of waves will extend to the tank bottom and thus be influenced by the bottom and its contour. A wave study to define the significant wave characteristics and wave spectra is planned for the near future. Until this is accomplished, it is difficult to intelligently argue the differences between test tank waves and wind driven waves, the latter already being statistically defined and categorized via wave spectra.

Apparently the turbulent effects of the waves tested were not significantly affected by the shallow, flat bottom. At least the effect on the critical current at which oil/HM entrainment begins was insignificant, in that good agreement with the well established value of 0.38 m/s (0.75 kt) for catenary booms was confirmed. However, the effect of a shallow, flat bottom on turbulence, orbital current and internal waves should be investigated and well defined.

There is an additional effect in the OHMSETT test tank that is perhaps unique--an air bubbler barrier system. The air barrier system is designed to protect the walls, beach and wave flaps as shown photographically in Figure 24.

Surface currents from the air bubbles (Figure 25) have been observed 6.1 m (20 ft) from the wall where they originated, and at speeds up to 0.3 m/s (0.6 kt) near the wall. Although accurate measurements have not been made, hydrodynamic principles dictate orbital currents and vertical velocitiy profiles generated by the rising air bubbles. The circulation pattern and velocity profiles are schematically shown in Figure 26. Here again, this effect should be defined with measurements and photographs to rigorously defend the test results and their relevance to the real world. Tests have been conducted with and without the air barrier with no measurable difference in results when testing with booms. This, plus the above mentioned agreement with the critical velocity of catenary booms on calm waters, tends to argue against the need for costly measurements of orbital circulation patterns and velocity profiles.

In conclusion, the test tank effects on the test data have not been quantitatively documented at OHMSETT. Qualitatively, effects can be argued to have had negligible influence on the test data of this particular project. However, until these effects are quantified, all OHMSETT data will not be rigorously proven to have a direct 1:1 relationship to the waterways and the real world.

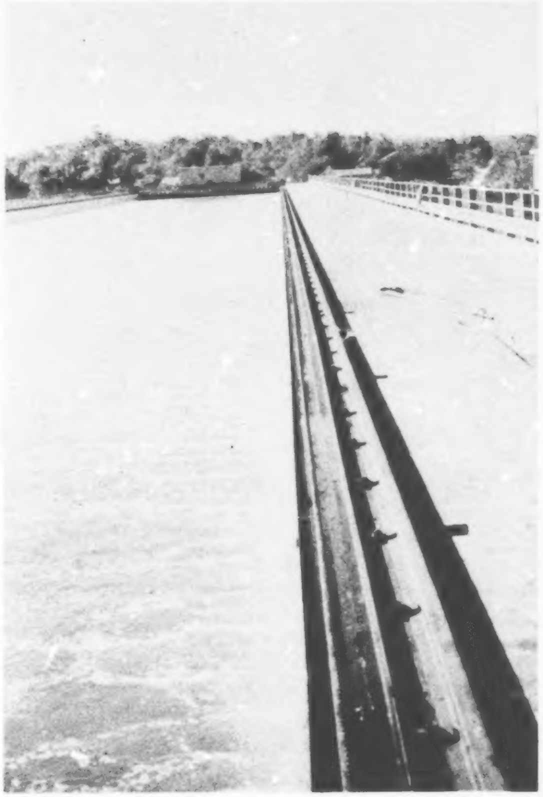

Figure 24. Photograph of air barrier surface currents

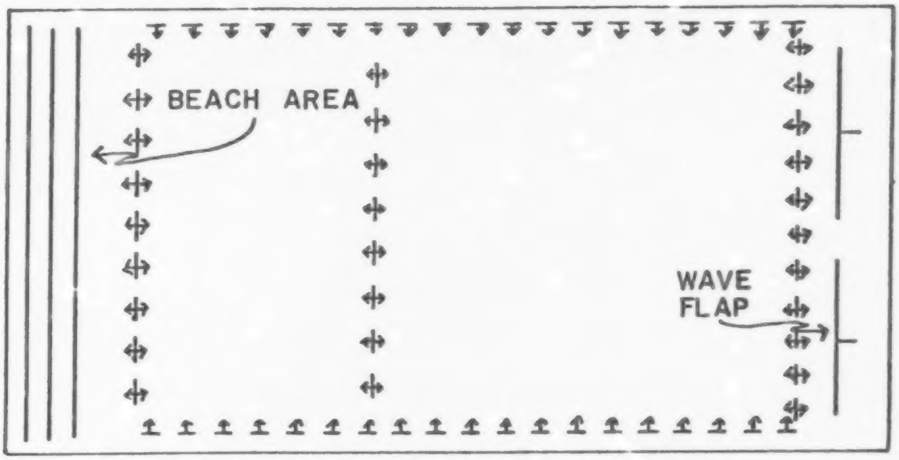

Figure 25. Air barrier surface currents.

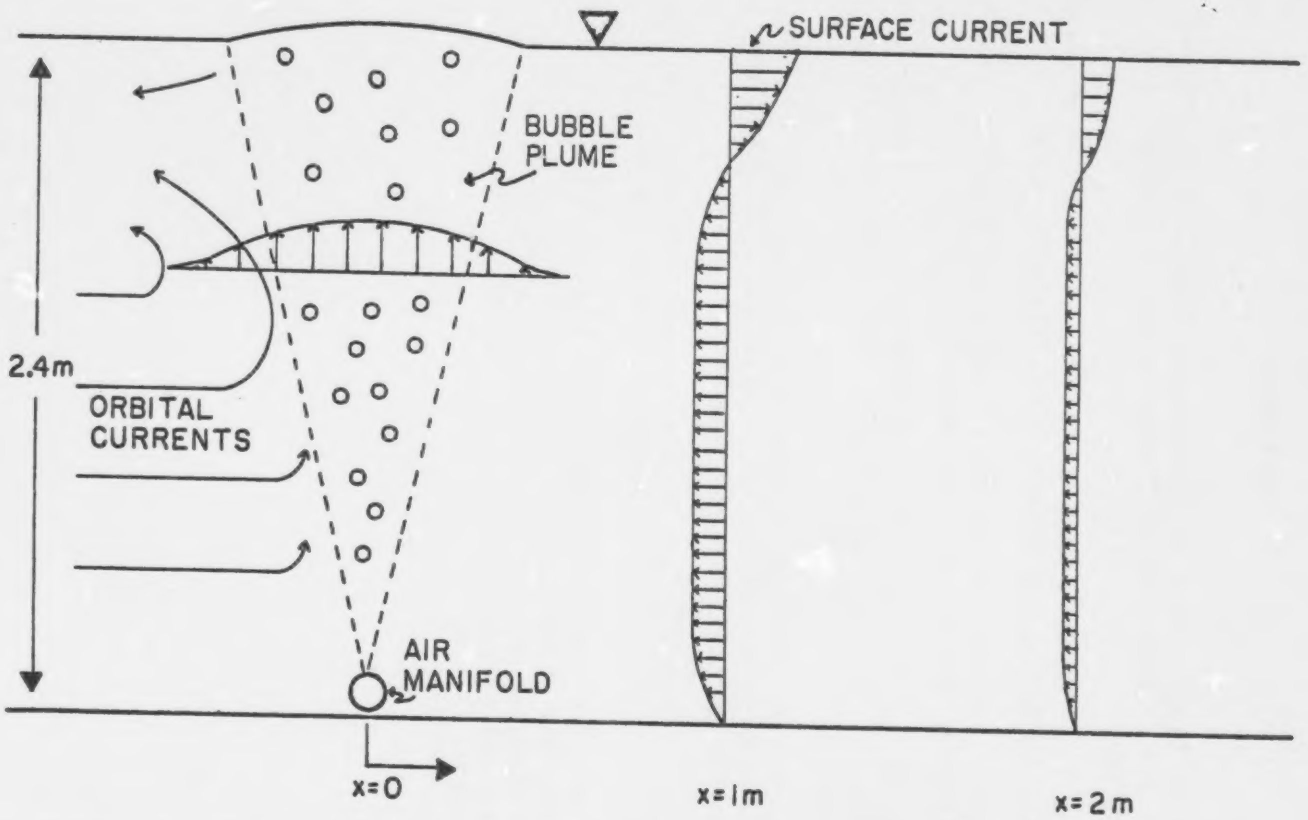

Figure 26. Circulation pattern and velocity profiles for an air barrier.

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APPENDIX A

OHMSETT DESCRIPTION

United States Environmental Protection Agency

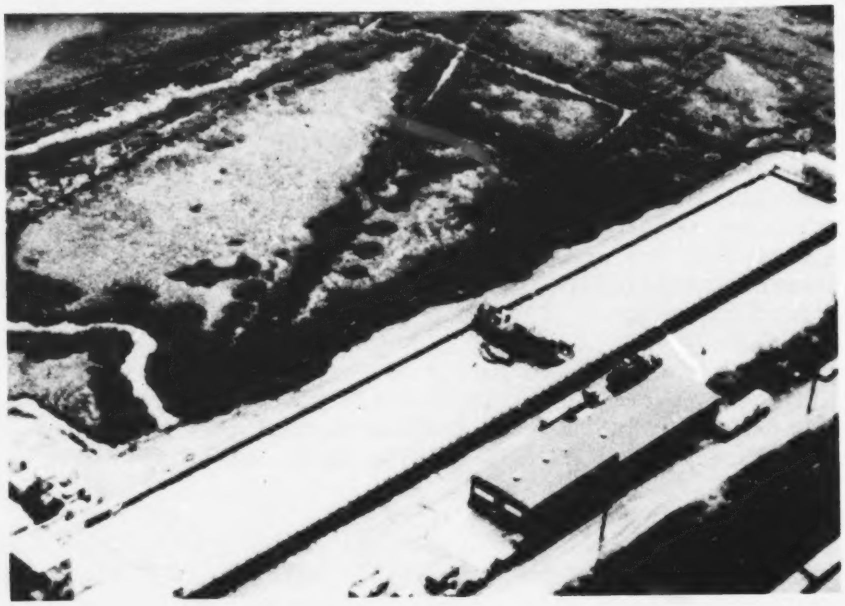

Figure A-1. OHMSETT.

The U.S. Environmental Protection Agency is operating an Oil and Hazardous Materials Simulated Environmental Test Tank (OHMSETT) located in Leonardo, New Jersey. This facility provides an environmentally safe place to conduct testing and development of devices and techniques for the control of oil and hazardous materials spills.

The primary feature of the facility is a pile-supported, concrete tank with a water surface 203.3 m (667 ft) long by 19.8 m (65 ft) wide and with a depth of 2.44 m (8 ft). The tank can be filled with fresh or salt water. The tank is spanned by a towing bridge with a capability of towing loads up to 15422.4 kg (34,000 lb) at speeds to 3.05 m/s (6 kt) for a duration of 45 seconds. Slower speeds yield longer test runs. The towing bridge is equipped to lay oil on the surface of the water several feet ahead of the device being tested, such that reproducible thicknesses and widths of oil slicks can be achieved with minimum interference by wind.

The principle systems of the tank include a wave generator and beach, a bubbler system and a filter system. The wave generator and absorber beach have capabilities of producing minimum reflection waves to 0.61 m (2 ft) high and 24.38 m (80 ft) long, as well as a series of reflecting, complex waves meant to simulate the water surface of a harbor or estuary. The water is clarified by recirculation through a 1.26 m^3/s (2,000 gal/min) diatomaceous earth filter system to permit underwater photography and video imagery, and to remove the hydrocarbons that enter the tank water a a result of testing. Oil is controlled on the surface of the water by a bubbler system which prevents oil from reaching the tank walls, the beach or the wave generator. This system is designed to speed clean-up between test runs. A clean tank surface is essential to reproducible oil spill conditions. The towing bridge has a built-in skimming board which, in conjunction with the bubbler system, can move oil to the North end of the tank for clean-up and recycling.

When the tank must be emptied for maintenance purposes, the entire water volume 9842 m^3 (2,600,000 gal) is filtered and treated until it meets all applicable State and Federal water quality standards before being discharged. Additional specialized equipment will be used whenever hazardous materials are used for tests. One such device is a trailer-mounted carbon adsorption unit which is availabe for removal of organic materials from the water.

Tests at the facility are supported from a 650 square meter building adjacent to the tank. This building houses offices, a quality control laboratory (which is very important since test oils and tank water are both recycled), a small machine shop, and an equipment preparation area.

This government-owned, contractor-operated facility is available for testing purposes on a cost-reimbursable basis to government agencies at the Federal, State and local levels. The operating contractor, Mason & Hanger-Silas Mason Co., Inc., provides a staff of eleven multi-disciplinary personnel. The U.S. Environmental Protection Agency provides expertise in the area of spill control technology, and overall project direction.

For additional information, contact:

OHMSETT Project Officer
U.S. Environmental Protection Agency
Research & Development
Edison, New Jersey 08817
Phone: 201-321-6600

APPENDIX B

PILOT STUDY

CONCLUSIONS

As a result of the pilot study, the following conclusions were reached:

- Octanol, dioctyl phthalate and naphtha are physically representative of the 167 HM investigated by Rensselaer Polytechnic Institute (RPI) for the U.S. Coast Guard, and would be used during the full-scale tests.
- The selected HM were relatively inexpensive, readily available and would respond to OHMSETT on-site processing.
- The selected HM were compatible with the materials of the test tank and ancillary equipment.
- Safety equipment and procedures for handling the HM were available at OHMSETT and Naval Weapons Station Earle.

INTRODUCTION

The determination to test oil-spill control equipment on floatable HM introduced a number of new considerations for planning of the OHMSETT tests. RPI, under contract to the U.S. Coast Guard, had reported on the compatibility of 167 HM with the materials used in the fabrication of oil-spill control equipment (7). The report was evaluated for candidate HM during the pilot study, and a further refinement made to select the minimum number of HM which would be representative of the large majority of those on the candidate-HM list.

OBJECTIVES

To expedite the selection of the HM to be used during testing, a pilot study was conducted on the use of HM at OHMSETT. Objectives were to:

- Make the final selection of the HM to be used during testing.
- Assure compatibility of the OHMSETT equipment with the selected HM.
- Develop safety procedures and practices to be used during testing.

Determine filterability.

TEST PLAN

It was determined that the pilot study would be conducted in three phases: a laboratory (jar test), during which the HM would be tested in combination with water to determine various physical properties; a test tank phase, during which tank materials and chemicals would contact the materials of construction in the OHMSETT test tank and ancillary equipment; and finally, pilot testing of the diatomaceous earth (d.e.) and activated carbon filters with the selected HM (see Tables B-1 and B-2).

SELECTION OF HM

The initial selection criteria for the chemicals to be used during OHMSETT testing were as follows:

1) Specific Gravity: Less dense than fresh water

2) Viscosity: Flowable at test temperatures

3) Flash Point: Greater than 80°F for fire safety reasons

4) Solubility: High degree of insolubility to reduce problems cleaning OHMSETT water

5) Toxicity: Low, to reduce hazards to personnel during testing

6) Odor: Inoffensive, since OHMSETT is an outdoor tank located near a residential neighborhood

7) Suitable for extended periods of exposure to testing personnel without adverse safety or health effects.

The 167 materials classified as floating hazardous substances by the U.S. Coast Guard were screened by RPI (7) on the basis of most of the above criteria. Three classes of materials were identified as suitable for testing: alkanes, aliphatic alcohols and esters. Seven materials were subsequently identified as being representative of these materials.

At the second stage of HM selection, the criteria were further refined to include cost, solubility, and the viscosity of the materials as supplied in large quantitites. The 167 materials selected were a low-vapor-pressure naphtha, octanol and dioctyl phthalate. The physical properties of the selected HM are shown in comparison to test oils in Table 1.

Initially, all the candidate HM were laboratory tested--octanol, decanol, dioctyl, adipate, naphtha and dioctyl phthalate; diesel oil was used as the control.

TABLE B-1. TEST MATRIX FOR PILOT D.E. FILTER SYSTEM

Test no.	HM	Filter media	Inlet concentrate	Flow rate (m^3/min)
1	#1	Normal	Saturated ix	7.6×10^{-4}
2	#1	Fine	" "	"
3	#1	Medium	" "	"
4	#1	Sorbo-Cel	" "	"
5	#1	Activated carbon	" "	"
6	#1	Combination	" "	"
7	#1	Chelating agent	" "	"
8 thru 14	#2	Repeat same conditions	" "	"
15 thru 21	#3	" " "	" "	"
22 thru 28	#4	" " "	" "	"
29 thru 35	#5	" " "	" "	"
36 thru 42	#6	" " "	" "	"

From the above tests, select the most promising HM, and run the following matrix:

1	TBD	TBD	Saturated	3.8×10^{-4}
2	"	"	1/2 Saturated onc.	7.6×10^{-4}
3	"	"	" " "	3.8×10^{-4}
4	"	"	1/4 Saturated conc.	7.6×10^{-4}
5	"	"	" " "	3.8×10^{-4}

TBD = To be determined

TABLE B-2. TEST MATRIX FOR PILOT ACTIVATED CARBON ADSORPTION SYSTEM

HM	D.E. filter media	No. of columns used	m^3/column
Octanol	Filter-Cel	4	22.7×10^{-3}
Octanol	Filter-Cel and Celite Sys	2	11.4×10^{-3}
Octanol	Filter-Cel	1	5.7×10^{-3}
Naphtha	Sorbo-Cel	4	22.7×10^{-3}
Dioctyl Phthalate	Filter-Cel	4	22.7×10^{-3}
Dioctyl Phthalate	Sorbo-Cel	4	22.7×10^{-3}

Pilot testing was conducted on candidate HM to determine the ability of the OHMSETT d.e. filtration plant and the mobile carbon adsorption trailer to remove any solubilized or emulsified HM from the tank water. Only octanol appeared to pose difficulties, since with agitation it tended to emulsify with water to a level of about 300 ppm. The biodegradability of octanol, however, was an offsetting factor, and water clean up problems were not judged severe.

Due to its flash point of 100°F, Naphtha was the greatest potential safety hazard. Several steps were taken to offset this hazard, including the strategic positioning of portable fire extinguishers, installation of a foam fire extinguishing system, and the installation of two independent systems for alarm and test system shutdown. One of these systems was a vapor concentration detector and the other was a heat detector. Additionally, during the Naphtha testing, a three-man U.S. Navy firefighting crew, from NWS Earle, with full equipment stood by at the site.

TEST APPARATUS DESCRIPTION

Jar Test Apparatus Description

The jar tests utilized a 8.0×10^{-4} m^3 blender to test for emulsion formation. A porcelain pan half-filled with OHMSETT water was used to determine the effect of HM on future testing with oil in OHMSETT.

Jar Test Procedure

The purpose of jar testing was to determine:

- Does the HM float?
- Can the HM be dyed for photographic purposes?
- Does the HM evaporate or degrade at a rate which would cause a problem?
- Will oil spreading be affected after these HM are used in OHMSETT?
- Does the HM emulsify when agitated with OHMSETT water, and, if so, will the emulsion break after a settling period?

To answer these questions, the following tests were performed with the results given in Table B-3:

1) A small amount of OHMSETT water was placed in a jar, and some of the HM placed in after it. The bottle was shaken sufficiently to break the interfacial tension between the fluids. If no HM could be seen on the bottom of the jar after a few minutes, the HM was considered floatable.

TABLE B-3. TEST RESULTS FOR JAR TESTS

		Octanol	Naphtha	Dioctyl Phthalate
1.	Does it float?	yes	yes	yes
2.	Can it be dyed?	yes	yes	yes
3.	Does it evaporate or degrade rapidly?	no	no	no
4.	Does it affect oil spreading?	no	no	no
5.	Does it emulsify?	yes	yes	yes
6.	Does emulsion break easily?	yes	yes	yes

TABLE B-4. TEST RESULTS FOR 1.13 m^3 TANK TESTS

		Octanol	Naphtha	Dioctyl Phthalate
1.	Are tank materials affected?	no	no	no
2.	Is chemical content of bubbler tank water being lowered?	yes	yes	yes
		217 ppm to 0 in 3-d	55 to 3 in 4-d	522 to 32 in 7-d

2) Various oil soluble dyes were mixed with the candidate HM. The mixtures were then placed into pans of OHMSETT water to determine whether the dye would be extracted into the water. O-red, red dye was finally chosen after consulting with the OHMSETT photographic technicians.

3) A pan was half filled with OHMSETT water and placed outdoors in a sunny location. The dyed test HM was placed on the water surface in the pan to a depth of 0.006 m (0.25 in). The pan was observed after 8 and 24 hours for any evaporation or visual degradation.

4) The pan used to determine the evaporation and degradation rates was cleaned by rinsing it under cold running water for about 30 seconds. OHMSETT water was placed in the pan, and No. 2 fuel oil and lube oil were placed on the surface of the water using an eye dropper. The spreading rates and patterns were compared with the rates and patterns exhibited in a non-contaminated pan.

5) A 50:50 sample of test HM/OHMSETT water was placed in a blender, and the blender was operated for 60 seconds. The time it took for the resulting emulsion to separate into HM and water layers was observed.

1.13 m^3 (300 gal) Tank Test Procedure

Four tanks were painted with the same paint used on the walls of OHMSETT (See Figure B-1).

Tank #1 - control--

Materials used in OHMSETT construction were placed in this tank, and the tank filled with OHMSETT water. Materials were observed for degradation.

Tank #2 - HM and materials--

Materials used in OHMSETT construction were placed in this tank along with one of the test HM and OHMSETT water. The materials and the HM were then observed for changes or degradation.

Tank #3 - bubbler and HM--

An air bubbling system was placed on the bottom of a tank as shown in Figure B-1 and attached to an air compressor. The tank was then filled with OHMSETT water and the bubbler turned on. A 0.001 m^3 (1 qt) volume of the test HM was placed on the surface of the tank inside the air bubbler and allowed to stand for four hours. After this period, any residual floating HM was removed. Grab samples of water were taken from the tank at this time and every 24 hours afterwards. The amount of test HM contained in the sample was analyzed by infrared spectrophotometer (See Table B-4 for results).

Tank #4 - Replacement (if required).

Figure B-1. 1.13 m^3 tank tests.

1-GPM Pilot D.E. Filter Plant Test Procedure

See Figures B-2 and B-3.

Before Each Set of Tests--

1) Clean and fill 1.89 m^3 (500 gal) tank with OHMSETT water before each test HM change.
2) Place 0.002 m^3 (2 qt) of test HM on surface of 1.89 m^3 (500 gal) tank
3) Turn on bubbler for approximately 2 h to mix HM in water
4) Turn off bubbler and allow tank to stand idle for 24 h.

Before Each Test--

1) Arrange pre- or post-treatment valves in position for either use or bypass of the carbon columns
2) Weigh out appropriate amount of the filter aide to be used
3) Precoat the filter with this filter aide while in recirculation mode
4) Start filter inlet pump and filter outlet pump
5) Place filter on stream
6) Adjust metering valves before and after filter to balance flow rates
7) At start up and at 1 h increments, take a 100 ml sample at filter inlet and filter outlet
8) If carbon columns were used, take start up and 1 h increment samples of the inlet and outlet streams
9) Stabilize and refrigerate sample and analyze by infrared spectrophotometer for test HM concentration (ppm)

TEST MATRIX

The matrix for the 3.8×10^{-3} m^3/min (1 gpm) d.e. pilot plant tests was designed to ensure that the proper filtration unit was used after the hazardous materials had been introduced into OHMSETT. Within this matrix, the intention was to duplicate the abilities of the test tank's d.e. filtration plant and carbon adsorption unit, and ensure proper selection of filtration media.

Each test was 24 h in duration.

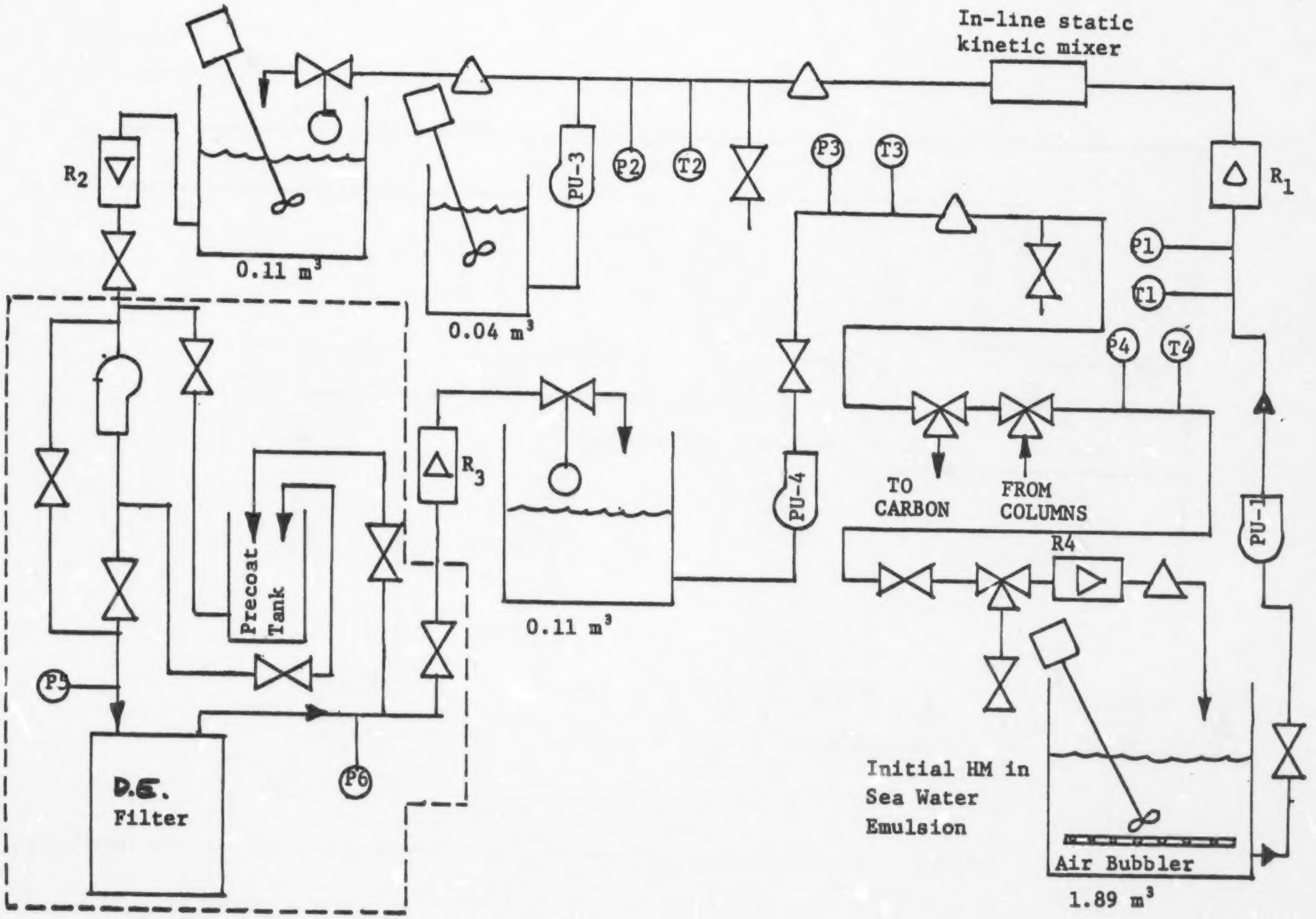

Figure B-2. HM pilot plant.

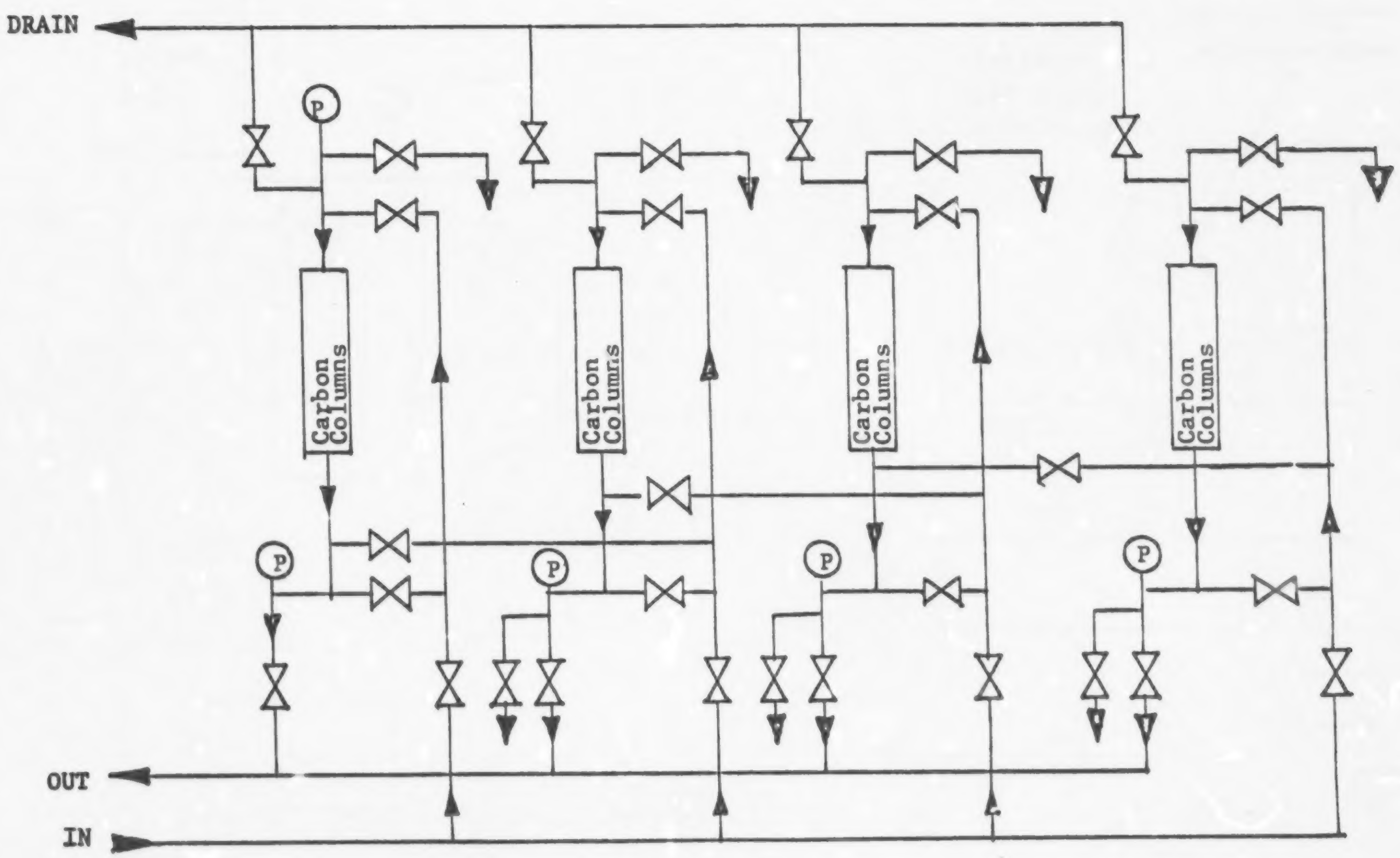

Figure B-3. Carbon column system.

DISCUSSION OF RESULTS

One of the principal questions to be answered before the test HM could be used in OHMSETT was whether or not the present filtering system could effectively remove the HM from the tank water, both for recycling purposes and for eliminating any negative effect on future performance testing with oil. Since the ability of the tank's filtering system to eliminate oil had been well established, the pilot plant was first tested with No. 2 fuel oil to ensure its effectiveness as a test device. Once this was established, the test HM were tested. From the beginning of the testing program it became obvious that the d.e. plant was not capable of completely removing the HM from the tank; therefore the model carbon adsorption unit was added to simulate the portable carbon unit available at OHMSETT for filtering purposes. Table B-5 shows the relative ineffectiveness of the d.e. filtration plant when used alone; the data in Table B-6 established the effectiveness of the dual filtration system.

TABLE B-5. TEST RESULTS FOR PILOT D.E. FILTER SYSTEM.

Test no.	Test HM	Filter media	Filter inlet (ppm)	Filter outlet (ppm)	Carbon inlet (ppm)
F-1	#2 Fuel	fine d.e.	375	175	---
F-2	"	fine d.e.	65	60	---
F-3	"	treated d.e.	50	70	---
F-4	"	treated d.e.	40	40	---
0-1	Octanol	coarse d.e.			
0-2	"	fine d.e.	700	475	---
0-3	"	medium d.e.	deleted		---
0-4	"	treated d.e.	330	330	---
0-5	"	fine d.e.	330	310	---
0-6	"	fine d.e.	315	315	---
0-7	"	fine d.e.	310	315	---
0-8	"	75% coarse d.e. + 25% powdered carbon precoated on filter	305	270	---
0-9	"	25% coarse d.e. + 75% powdered carbon precoated on filter	295	290	---
0-11	"	"	95	----	---
0-12	"	50% coarse + 50% fine d.e. on filter plus 2 carbon columns post-treatment	190	----	---

(Continued)

TABLE B-5 (Continued)

Carbon outlet (ppm)	Contact time (min)	Flow rate $m^3/s \times 10^{-5}$ (gpm)	Comments	Test no.
----	----	9.5 (1.5)		F-1
----	----	10.3 (1.7)		F-2
----	----	9.6 (1.6)		F-3
----	----	9.5 (1.5)		F-4
----	----	12.1 (2.0)	Failure observed visually; dyed chemical was present downstream of filter.	0-1
----	----	6.3 (1.0)		0-2
----	----	---- ----		0-3
----	----	11.4 (1.8)		0-4
----	----	6.9 (1.1)		0-5
----	----	6.9 (1.1)	Within accuracy of results with filter was not removing chemical.	0-6
----	----	6.9 (1.1)	" " "	0-7
----	----	9.6 (1.6)		0-8
----	----	9.5 (1.5)	" " "	0-9
< 5	5.6	6.9 (1.1)		0-10
< 5	5.6	6.9 (1.1)		0-11
10	3.0	6.3 (1.0)		0-12

TABLE B-6. TEST RESULTS FOR D.E. FILTER & ACTIVATED CARBON ADSORPTION SYSTEM

Test no.	Test HM	Filter media	Filter inlet (ppm)	Filter outlet (ppm)	Carbon inlet (ppm)
O-13	"	fine d.e. on filter plus 1 carbon column post-treatment	130	---	60
N-1	Naphtha	fine d.e.	40	30	---
N-2	"	" "	40	35	---
N-3	"	treated d.e.	35	30	---
N-4	"	treated d.e. on filter plus 4 carbon columns post-treatment	35	30	30
N-5	"	"	15	10	10
D-1	Dioctyl Phthalate	fine d.e. on filter plus 4 carbon columns post-treatment	30	10	10
D-2	"	"	35	30	30
D-3	"	"	45	40	40
D-4	"	"	9	8	8
D-5	"	treated d.e. on filter plus 4 carbon columns post-treatment	12	9	9
D-6	"	treated d.e. on filter plus 4 carbon columns post-treatment	26	15	15
D-7	"	"	22	11	11

(Continued)

TABLE B-6 (Continued)

Carbon outlet (ppm)	Contact Time (min)	Flow rate $m^3/s \times 10^{-5}$	(gpm)	Comments	Test no.
60	1.5	6.3	(1.0)		0-13
---	---	10.3	(1.7)		N-1
---	---	8.8	(1.4)		N-2
---	---	9.5	(1.5)		N-3
10	3	12.6	(2.0)	Suspected carbon columns were saturated and leakage of HM began.	N-4
10	3	12.6	(2.0)	" " " "	N-5
0	5.0	5.0	(0.8		D-1
0	2.5	9.6	(1.6)		D-2
0	2.5	9.6	(1.6)		D-3
0	2.8	8.8	(1.4)		D-4
0	2.5	9.6	(1.6)		D-5
0	2.7	9.5	(1.5)		D-6
0	2.5	9.6	(1.6)		D-7

APPENDIX C

TEST EQUIPMENT - BOOMS

The following section of this report describes the individual boom systems tested. Individual systems are detailed in the following manner:

Manufacturer - Name of system

Design characteristics

Tow point connections

Comments

Diagrams and photographs of devices, sketches of tow point connections, and rigging specifications are given separately following the above details in this appendix. Catenary and diversionary rigging details are given in Figures C-1, C-2, and Table C-1.

Technical information contained herein is reprinted courtesy of the individual manufacturers.

CLEAN WATER, INC. - HARBOUR OIL CONTAINMENT BOOM

Design Characteristics (See Figures C-3, C-4, and C-5)

(1) Draft - 0.61 m (24 in)

(2) Freeboard - 0.20 m (8 in)

(3) Floatation - expanded polyethylene cylinders, 0.15 m dia. x 0.46 m long (6 in x 18 in)

(4) Ballast - 0.635 cm galvanized chain, pocketed along bottom of skirt

(5) Skirt material - nylon reinforced resistant PVC heavy duty sheet encasing

(6) Tension member - 0.749 cm dia. coated aircraft cable threaded through float cylinders. Second tension member is ballast chain

(7) Weight - 3.04 kg/m (2.04 lb/ft)

(8) Excess buoyancy - 4.02 kg/m (2.70 lb/ft)

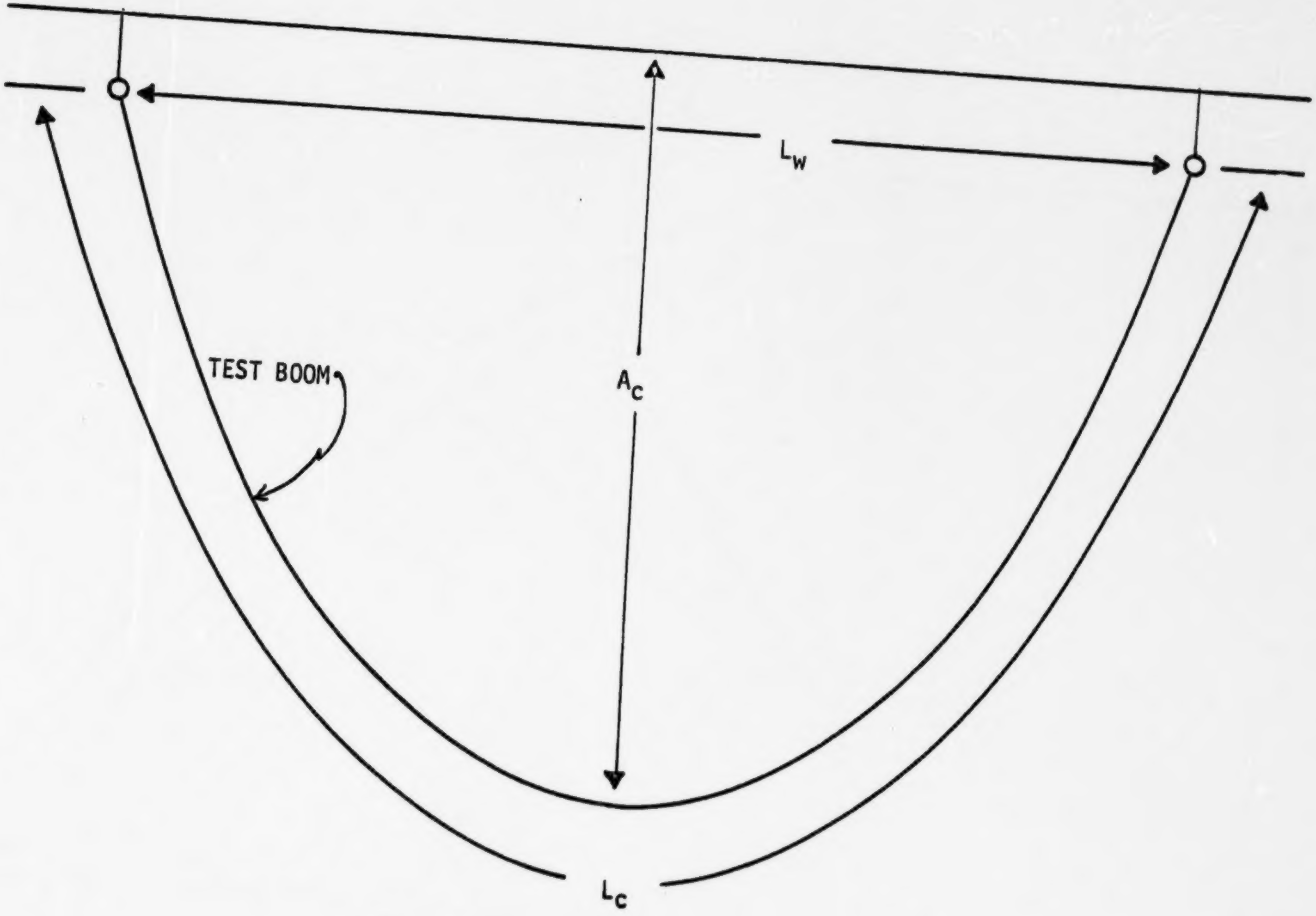

Figure C-1. Catenary rigging details.

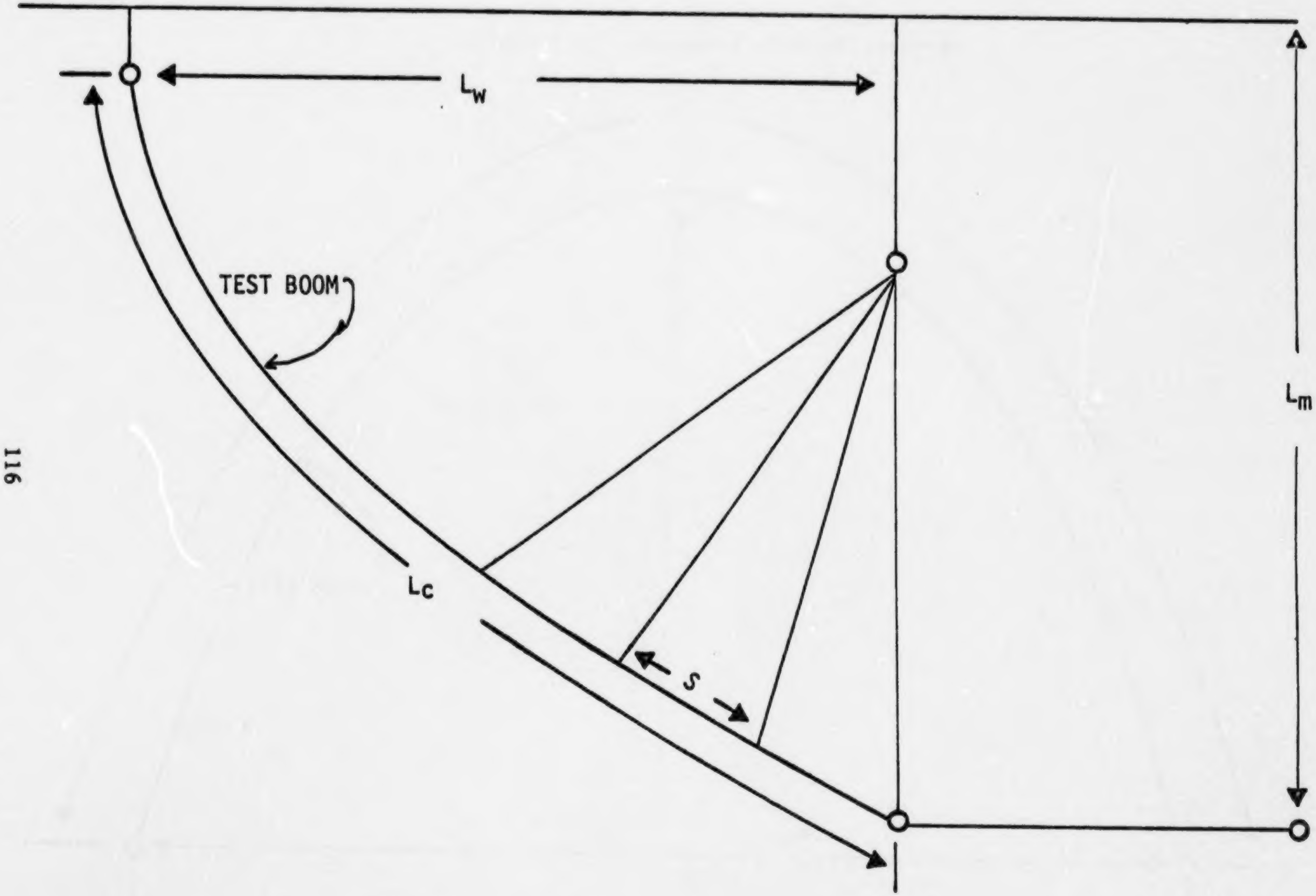

Figure C-2. Diversionary rigging details.

TABLE C-1. SUMMARY OF RIGGING SPECIFICATIONS

	Catenary			Diversionary			
Boom	L_c (m)	L_w (m)	A_c (m)	L_c (m)	L_w (m)	L_m (m)	S (m)
Clean Water	61.0	18.6	23.5	30.5	18.6	26.2	7.6
B.F. Goodrich	56.7	18.6	25.9	29.3	18.6	28.7	8.5
U.S. Coast Guard	57.9	18.6	27.4	----	----	----	---

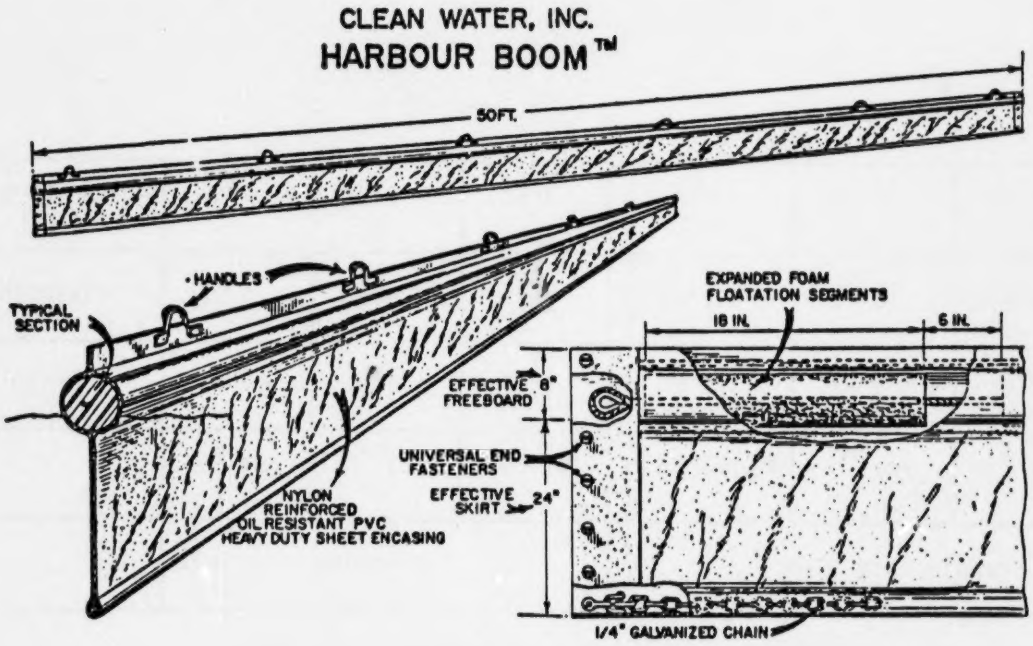

Figure C-3. Clean Water Boom details.

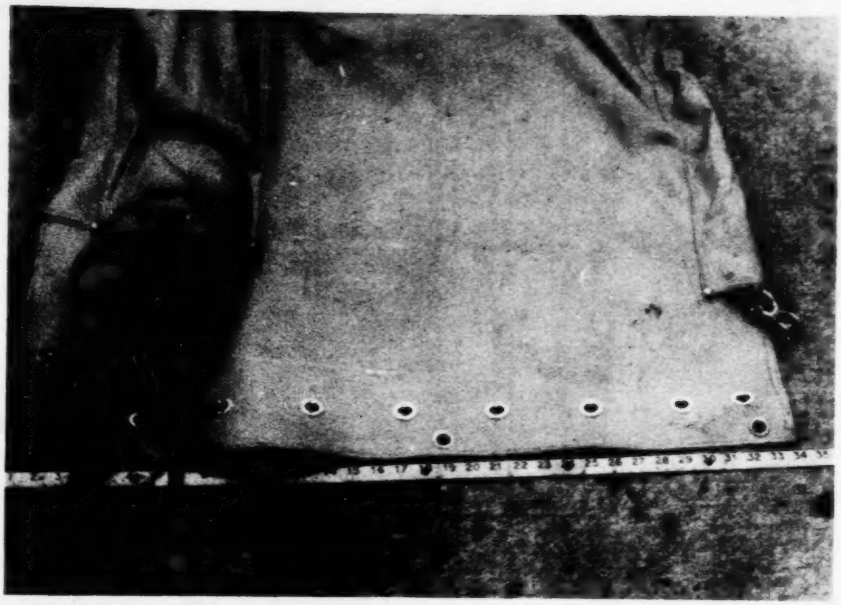

Figure C-4. Clean Water Boom.

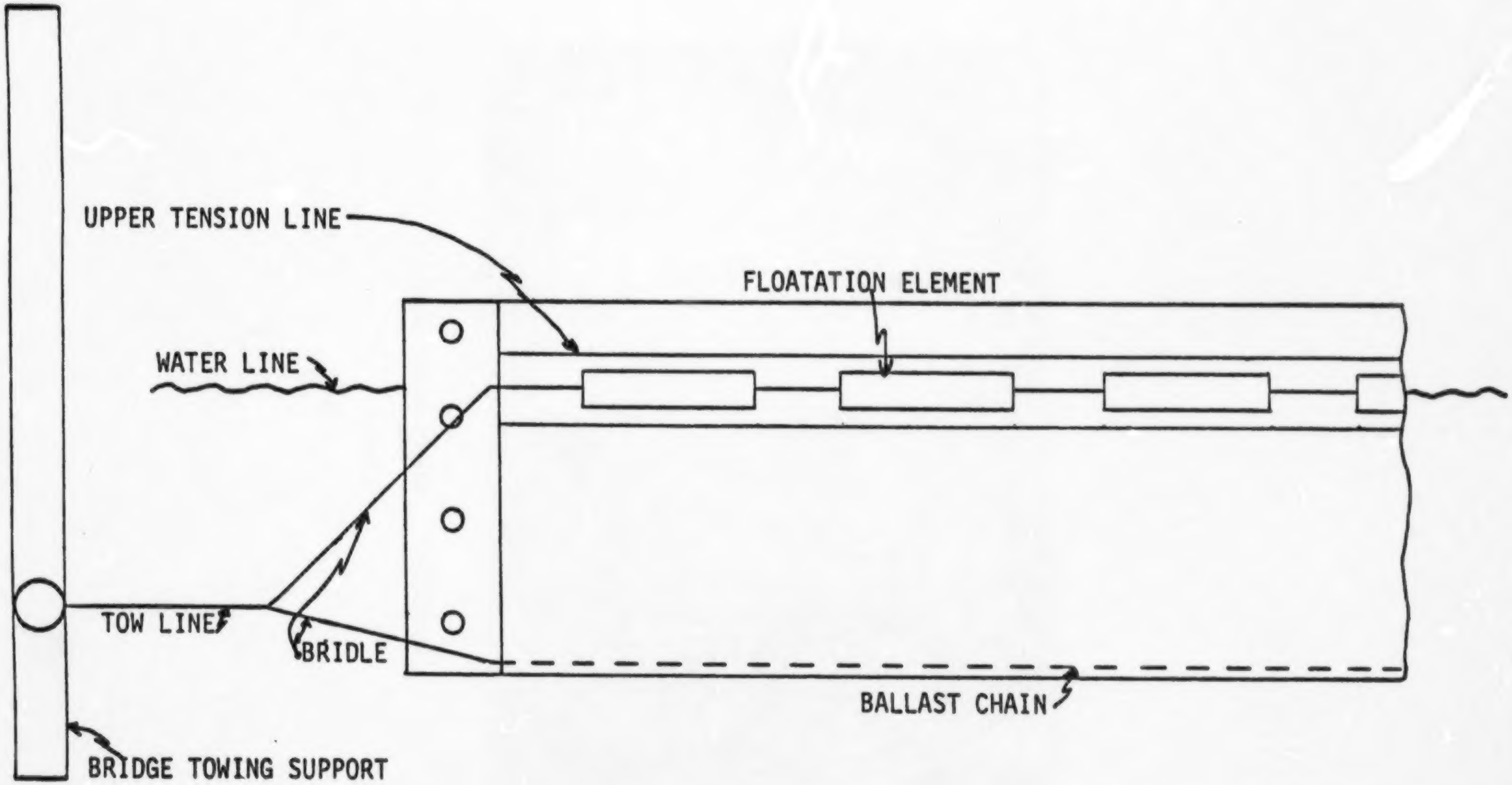

Figure C-5. Clean Water boom tow point connection.

(9) Available in 15.2 m sections (50 ft)

Tow Point Connection

(1) A bridle arrangement was connected top and bottom to coated aircraft cable and ballast chain. This then was connected to bridge tow points.

Comments

(1) Reticulation between floatation elements facilitated handling and storage, but slackened during test runs causing loss of freeboard. The addition of slack retaining lines at these points would reduce this effect.

(2) Required three men per section for handling and was relatively easy to deploy and make connections.

B.F. GOODRICH - SEABOOM

Design Characteristics (See Figures C-6, C- 7, and C-8

(1) Draft - 0.30 m (12 in)

(2) Freeboard - 0.15 (6 in)

(3) Floatation - continuous chambers of closed cell foam, protected by 0.635 cm PVC coating and secured at the boom ends with wooden plugs

(4) Ballast - tubular, extrusion filled with lead shot and sand

(5) Skirt material - 0.635 cm thick vinyl sheet reinforced with rib-handles of urethane

(6) Tension member - self-tensioning boom

(7) Weight - 11.01 kg/m (8.0 lb/ft)

(8) Excess buoyancy - 10.42 kg/m (7.0 lb/ft)

(9) Standard length - 7.16 m (23.5 ft)

Tow Point Connection

(1) A bridle arrangement was connected to the manufacturer-provided "SEALOC" system. This consists of a piano hinge arrangement with fiberglass pins.

Comments

(1) Required 10 men per section for handling, and a crane for deployment and removal.

B.F.Goodrich **seaboom™**

18" SEABOOM (PFX AND SU)

The most versatile of all Seabooms, so tough it normally will last far beyond the Seaboom two year warranty. Strong and streamlined, 1,000 feet can be towed at high speed from place to place. Appropriate for harbors, bays, rivers and limited open sea use.

	18PFX	18SU
Freeboard	6"	6"
Draft	12"	12"
Weight	7.5 lbs./ft.	11 lbs./ft.
Standard Length	23.5'	23.5'
Working Strength	6,000 lbs.	8,000 lbs.
Reserve Buoyancy	7 lbs./ft.	4 lbs./ft.
Stability	Very High	Very High
Volume/Std. Length	11.2 ft.³	11.2 ft.³

Figure C-6. B.F. Goodrich Boom details.

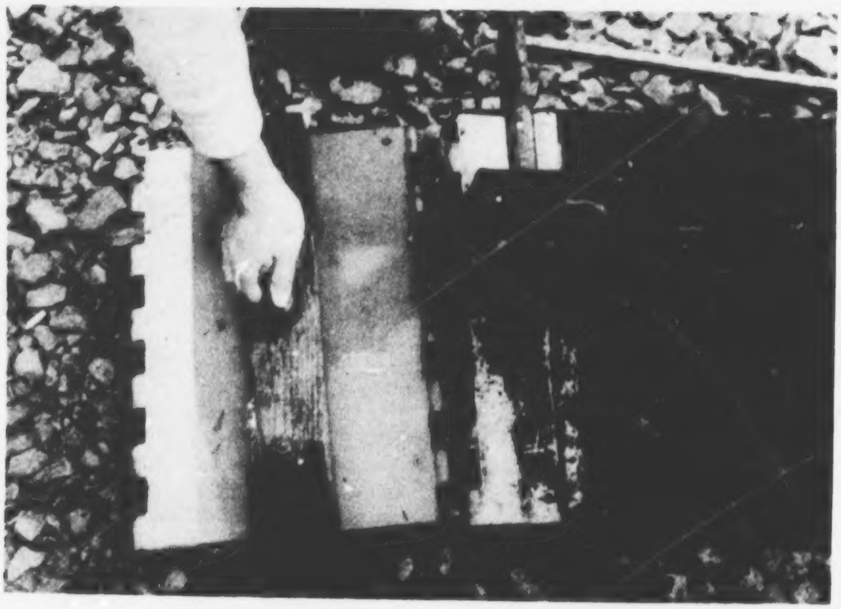

Figure C-7. B.F. Goodrich Boom.

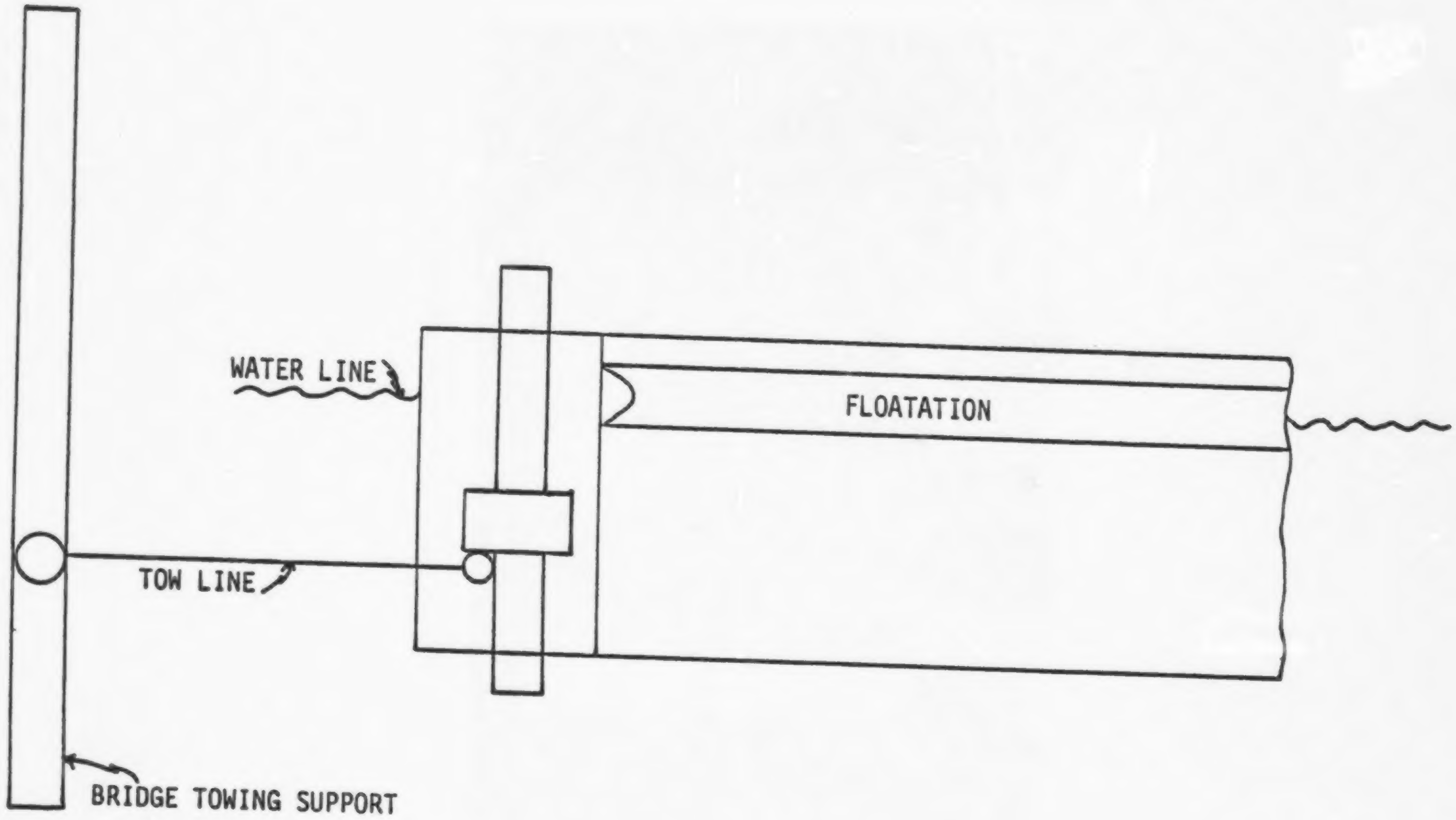

Figure C-8. B.F. Goodrich boom tow point connection.

(2) Attaching end plates and making section connections were easy.

U.S. COAST GUARD - PROTOTYPE HIGH SEAS BARRIER

Design Characteristics (See Figures C-9, C-10, and C-11)

(1) Draft - 0.69 m (2.25 ft)

(2) Freeboard - 0.53 m (1.75 ft)

(3) Floatation - air filled cylinders 1.82 m long x 0.36 m dia. (6 ft x 14 in), equally spaced at 1.96 m (77 in) intervals

(4) Skirt material - 2 ply elastomer coated nylon

(5) Tension member - 3.33 cm (1.32 in) dia. external tension line (rope)

(6) Weight - 20.83 kg/m (14 lb/ft)

(7) Excess buoyancy - 74.4 kg/m (50 lb/ft)

Tow Point Connection

(1) A direct connection was made by means of eye bolts and clevis connectors to the external tension line.

Comments

(1) Floatation sections tended to "jump" bottom tension line during some test runs causing localized loss of test fluids.

(2) At slow speed (< .51 m/s), interfloat regions of freeboard slackened, causing boom to lose proper vertical profile.

(3) Vortex currents observed at the apex of floatation cylinders caused test HM to escape.

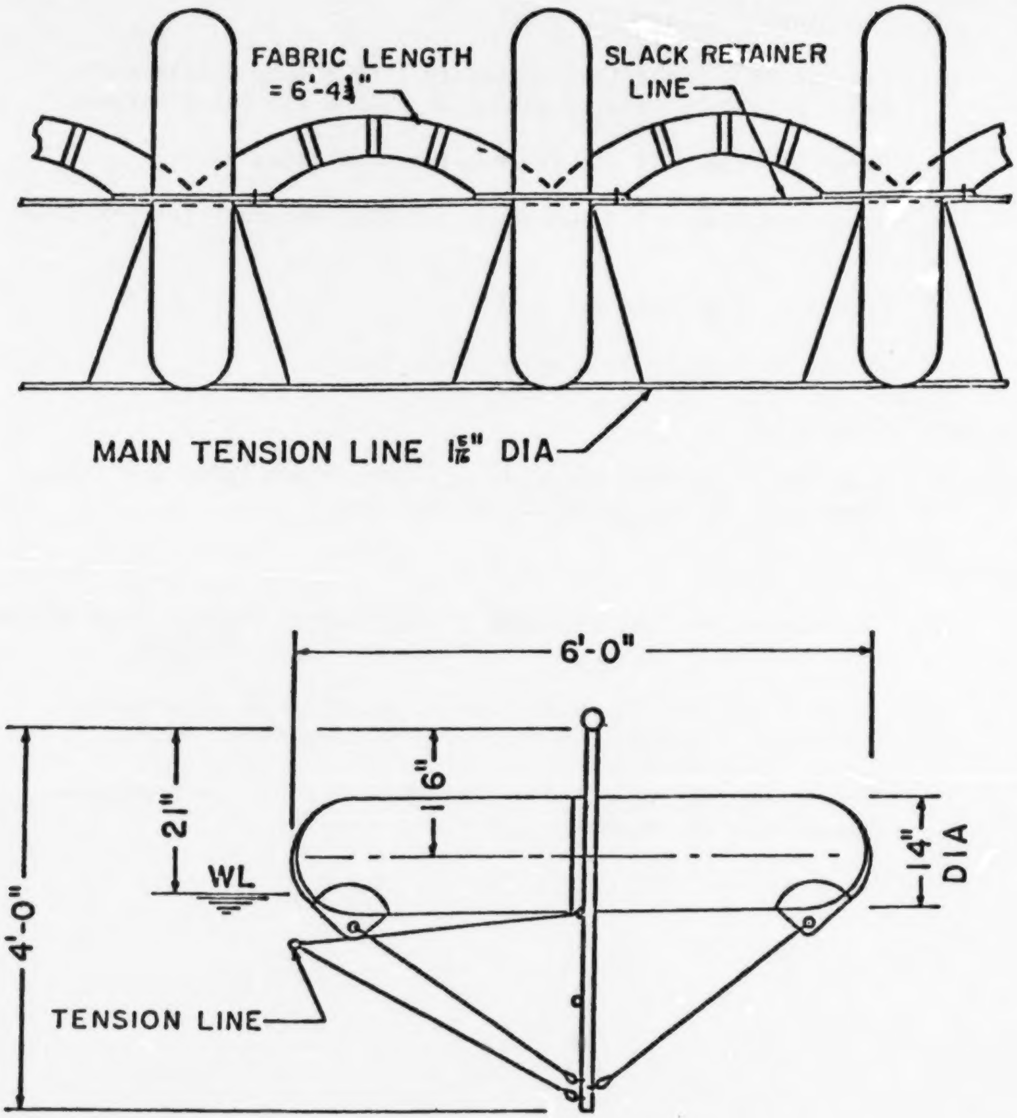

Figure C-9. U.S. Coast Guard Prototype High Seas Barrier Details.

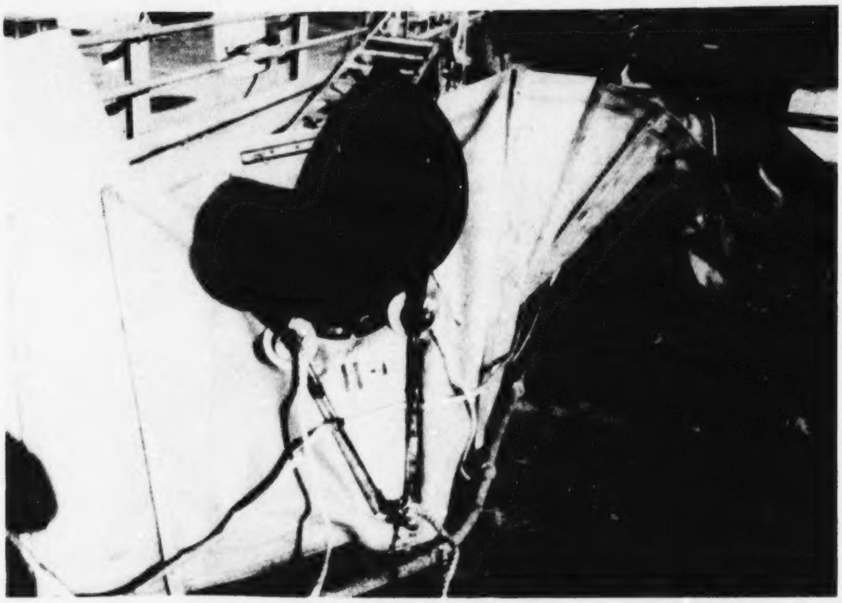

Figure C-10. U.S. Coast Guard Prototype High Seas Barrier.

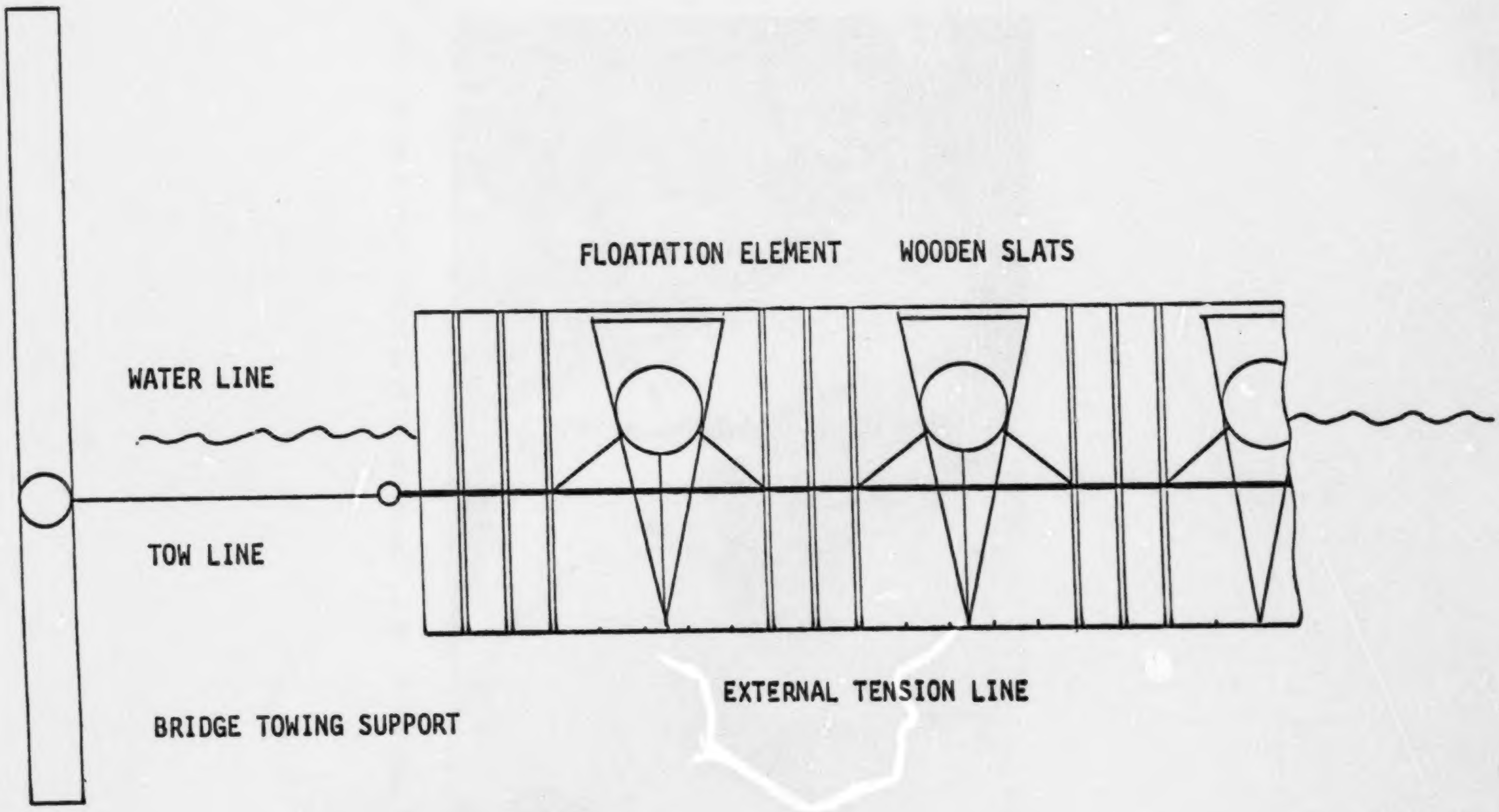

Figure C-11. U.S. Coast Guard Prototype High Seas barrier tow point connection.

APPENDIX D

TEST EQUIPMENT - STATIONARY SKIMMERS

The following section of this report describes the individual skimmer systems tested. Individual systems are detailed in the following manner:

Manufacturer - Name of system

Design characteristics

Pump data

Diagrams and photographs are given separately following the above details in this appendix (see Figures D-1, D-2, and D-3).

Certain materials are reprinted courtesy of the individual manufacturers.

SLICKBAR 1 IN. RIGID MANTA RAY

Design Characteristics

(1) Size - 0.03 m opening by 1.22 m dia (1 in x 48 in)

(2) Weight - 11.3 kg (25 lb)

Pump

(1) Type - twin diaphragm, self priming

(2) Hose - 0.10 m (4 in) I.D. floating suction hose, 3.05 m (10 ft) lengths

(3) Capacity - 1.1×10^{-2} m^3/s (178 gpm)

I.M.E. - SWISS OELA III

Design Characteristics

(1) Height - 0.39 m (15.2 in)

(2) Weight - 49.9 kg (110 lb)

Pump

(1) Type - twin diaphragm, air operated

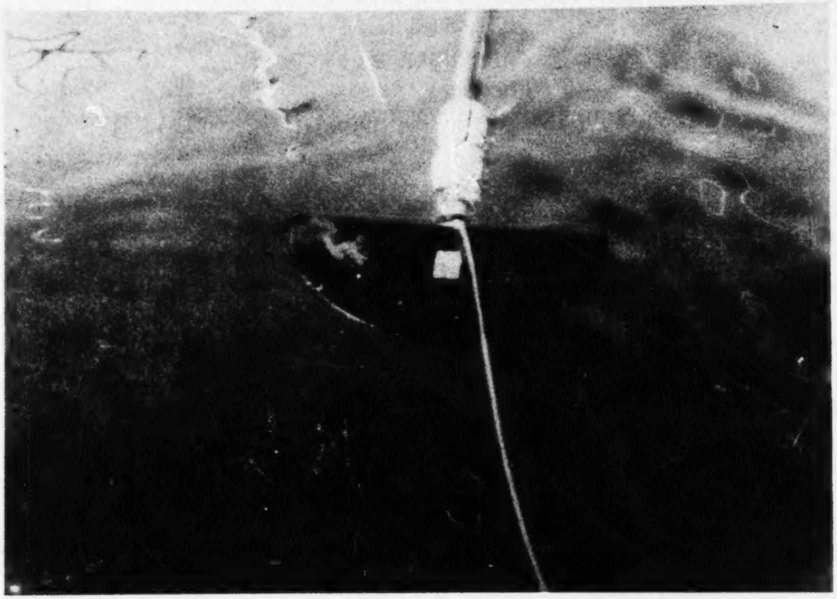

Figure D-1. Slickbar skimmer.

Figure D-2. I.M.E. skimmer.

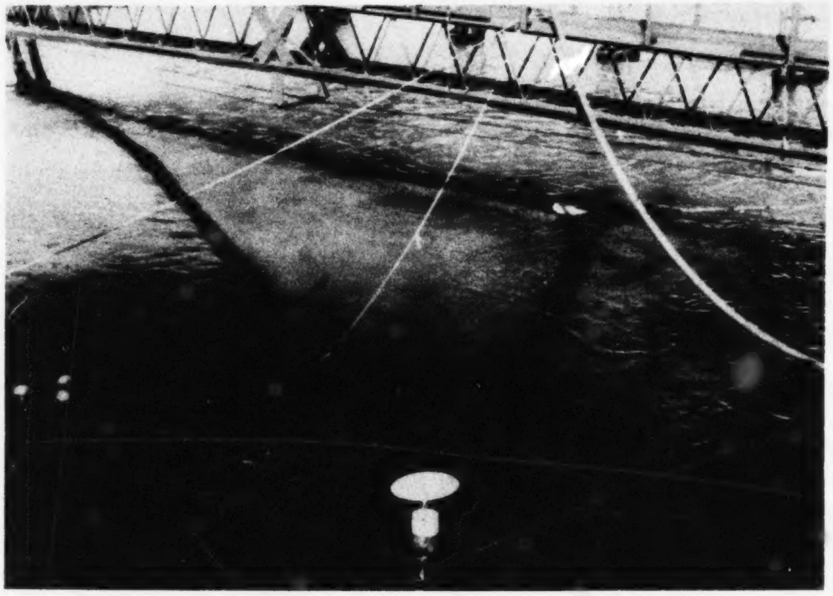

Figure D-3. Oil Mop skimmer.

APPENDIX E

TEST EQUIPMENT - ADVANCING SKIMMERS

The following section of this report describes the individual skimmer system tested. Individual systems are detailed in the following manner:

Manufacturer - Name of system

Design Characteristics

Pump data

Diagrams and photographs are given separately following the above details in this appendix (see Figures E-1, E-2, and E-3).

Certain materials are reprinted courtesy of the individual manufacturers.

JBF SCIENTIFIC CORP. - DIP 1002 SKIMMER

General Description

The DIP (Dynamic Inclined Plane) is a floating, portable endless-belt skimmer which is operated from a vessel or pier through a 25 ft (7.6 m) control wand (see Figure E-1).

Overall Dimensions

1.8 m x 1.1 m x 0.9 m high (5.9 ft x 3.6 ft x 2.9 ft)

Weight

272.2 kg (600 lb)

Pump Type

Positive displacement, air diaphragm pump

Pump Rate

3.2×10^{-3} m^3/s at 5.5×10^5 N/m^2 (50 gpm at 80 psi)

Discharge Hose

0.05 m diameter

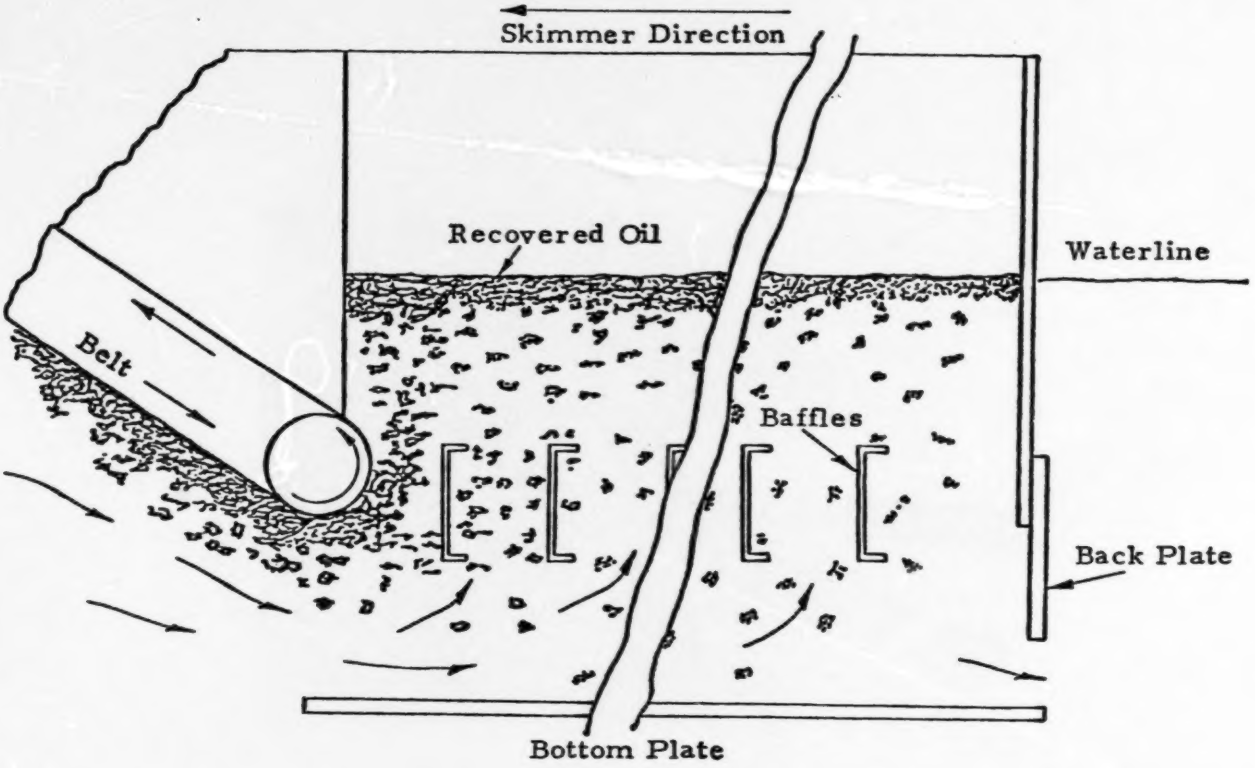

Figure E-1. Basic principle of operation of the DIP skimmer.

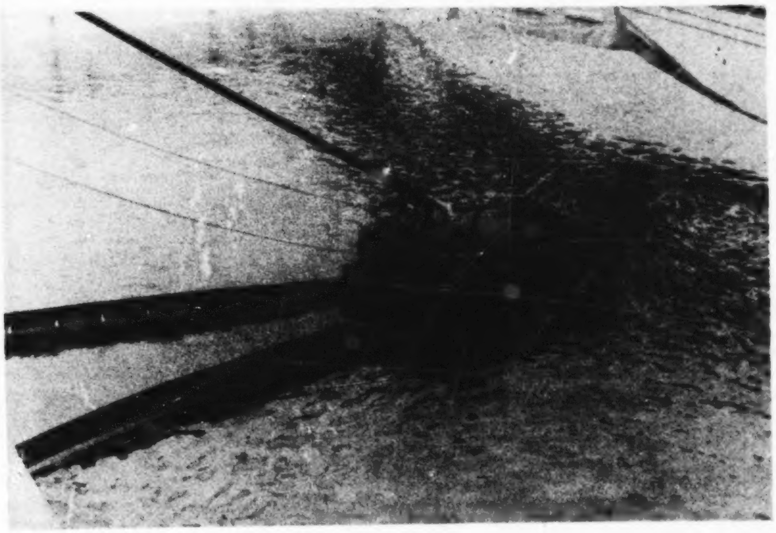

Figure E-2. DIP skimmer.

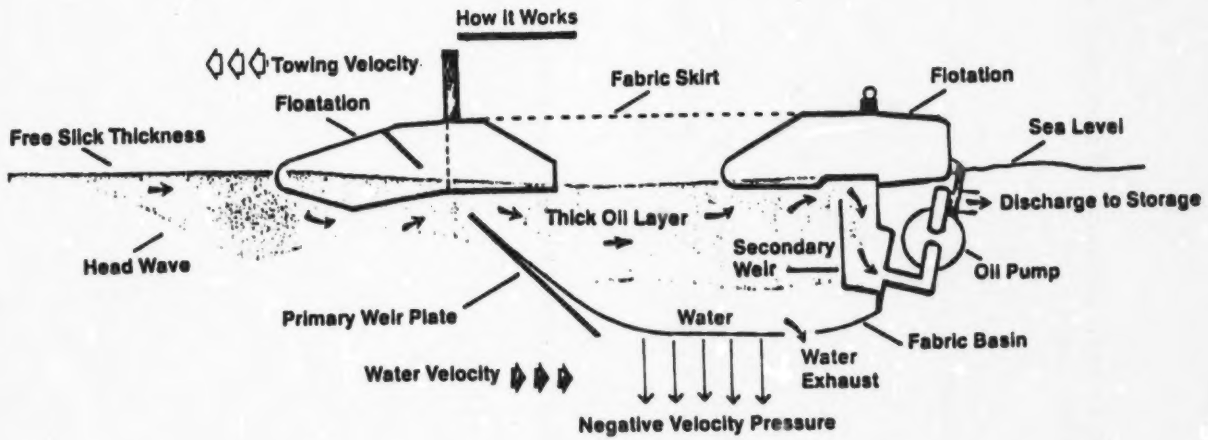

Figure E-3. Basic principle of operation of the ORS skimmer.

Belt

Polyurethane or PVC

ORS-125 HARBOR OIL RECOVERY SYSTEM

General Description

The ORS-125 is a double weir-type skimming system used as a link at the apex of a funneling boom (see Figure E-3).

Overall Dimensions

1.2 m x 1.2 m x 2.1 m (skimmer); 0.6 m x 0.6 m x 0.6 m (pump)

Weight

154.2 kg (343 lbs)

Pump Type and Capacity

Double diaphragm air operated, rated for 7.9 x 10^{-3} m^3/s (125 gpm) of 43.2 x 10^{-6} m^2/s) (0.43 cSt) oil; or 6.3 x 10^{-3} m^3/s (100 gpm) of 863.9 x 10^{-6} m^2/s (8.6 cSt) oil.

Discharge Hose

0.08 m dia; 45.7 m long lightweight collapsible fuel hose supplied.

APPENDIX F

TEST EQUIPMENT - U.S. EPA/SEAWARD SORBENT SYSTEM

The Sorbent System consists of three separate units: broadcaster, recovery unit and regenerator. The broadcaster distributes 3/4 in polyurethane cubes onto the surface of a slick, so that the cubes absorb the oil or HM (Figure F-1). The recovery unit is a conveyor belt device which is towed into a slick and is contained in booms that are in a V-shaped configuration stretching out from the recovery unit. The cubes are removed from the slick by the recovery unit's conveyor belt, which deposits them in a bin behind the unit (Figure F-2). The bin is removed to the regenerator (Figure F-3), where the cubes are squeezed dry while passing through rollers. The fluid-free cubes are returned to the broadcaster and redistributed. Detailed specifications of the U.S. EPA/Seaward Sorbent System are available in Reference 6.

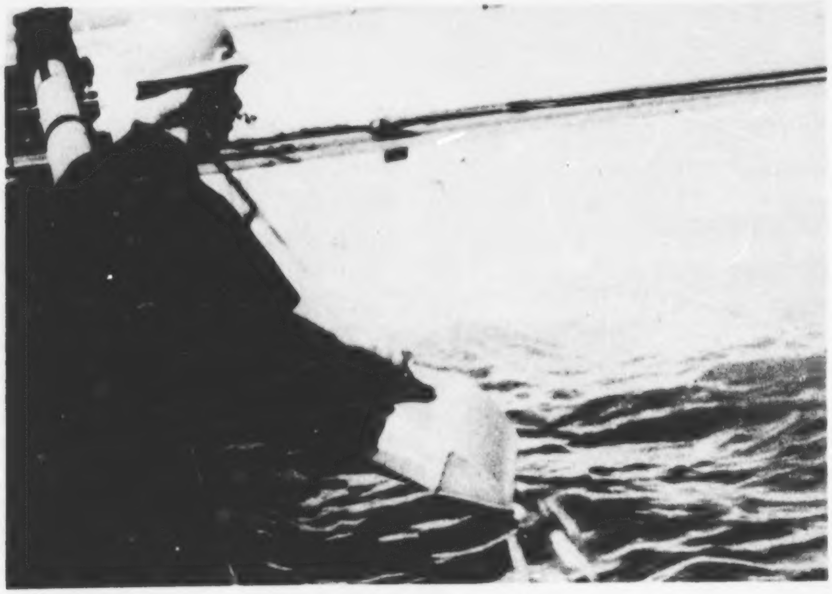

Figure F-1. The broadcaster.

Figure F-2. The recovery unit.

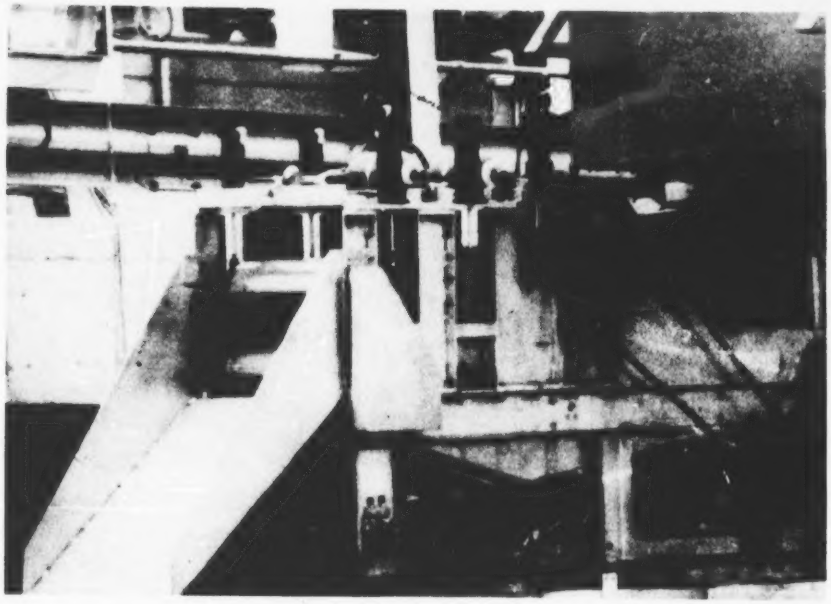

Figure F-3. The regenerator.